ARM Atmospheric Radiation Measurement Program

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Using Basic Surface Radiation and Met Measurements to infer Cloud Properties

C. N. Long, J. C. Barnard,
J. Calbo, T. P. Ackerman
K. Gaustad, and others…

Introduction

- We have some sophisticated surface cloud and radiation sites
  - Retrieval of cloud properties, especially microphysical
  - Used for developing, improving, & testing models & satellite retrievals
  - Costly, thus only a few
- Many surface radiative energy budget and meteorological sites
  - Have made progress toward more accurate measurements (BSRN) through deployment of SW direct and diffuse measurement capability

Intent of research

- Idea: glean all possible cloud info of reasonable and useful certainty from typical surface rad. & met. meas.
- For use:
  - in climatological studies
  - as ground truth for model/satellite comparisons

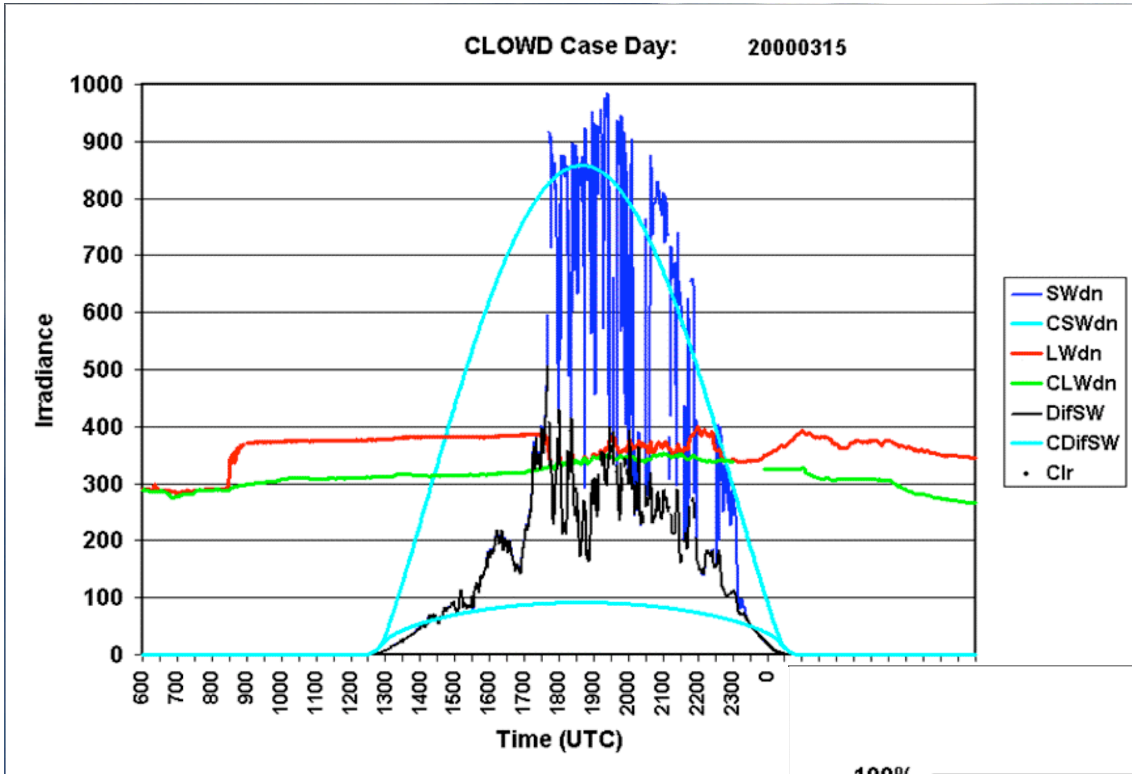
Flux Analysis

- SW Flux Analysis (SWFA) code
  - Detection of clear (i.e. cloudless) sky periods using Long and Ackerman (2000)
  - Empirically fit functions, interpolate for cloudy periods
  - Produce continuous estimates of clear-sky downwelling global, direct, and diffuse SW
  - Infer fractional sky cover for solar elevations of 10^{O} and greater
  - Currently available as an ARM VAP

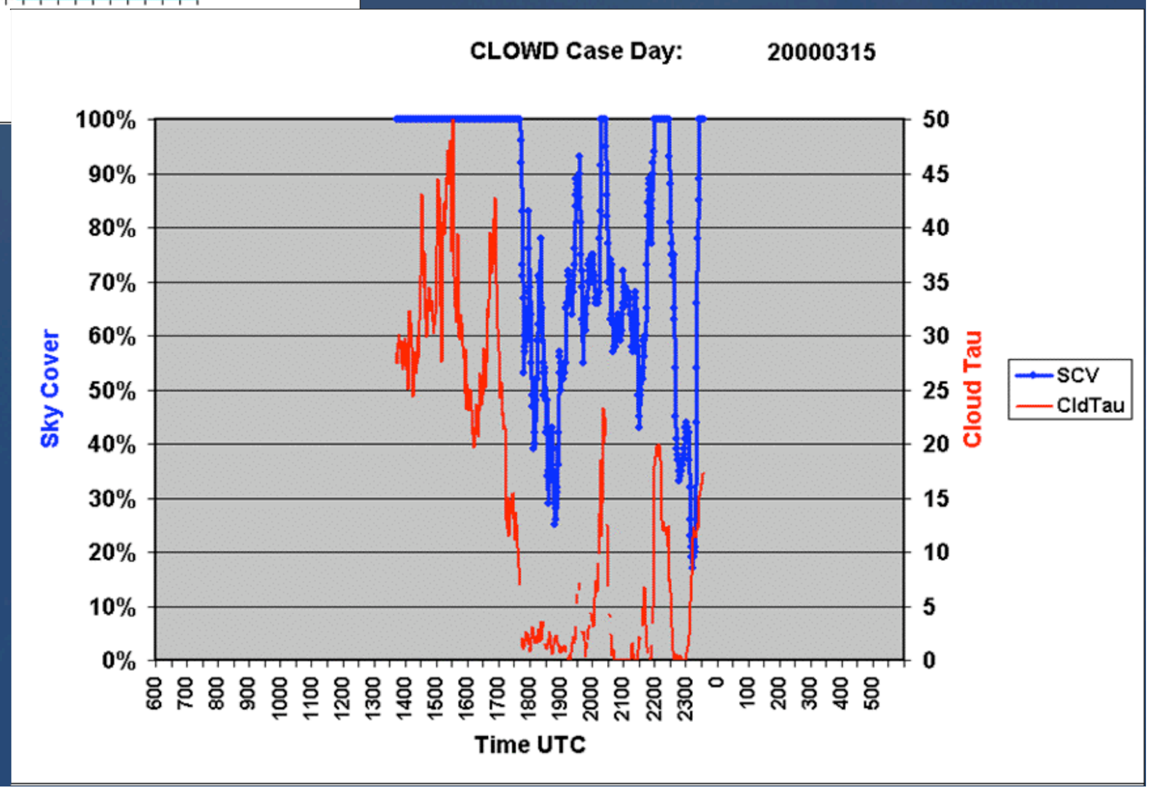
Cloud Optical Depth

- Effective plane-parallel spherical droplet cloud optical depth
  - Based on Min and Harrison, 1996, GRL.
  - Barnard and Long, 2004, JAM, empirical formulation
    - (incl. sfc. albedo and asymmetry parameter)
  - Known to overestimate for small optical depths
  - Use independent pixel approximation arguments for partly cloudy skies
- Needs refinement for water/ice

Example



ARM SGP 20000315



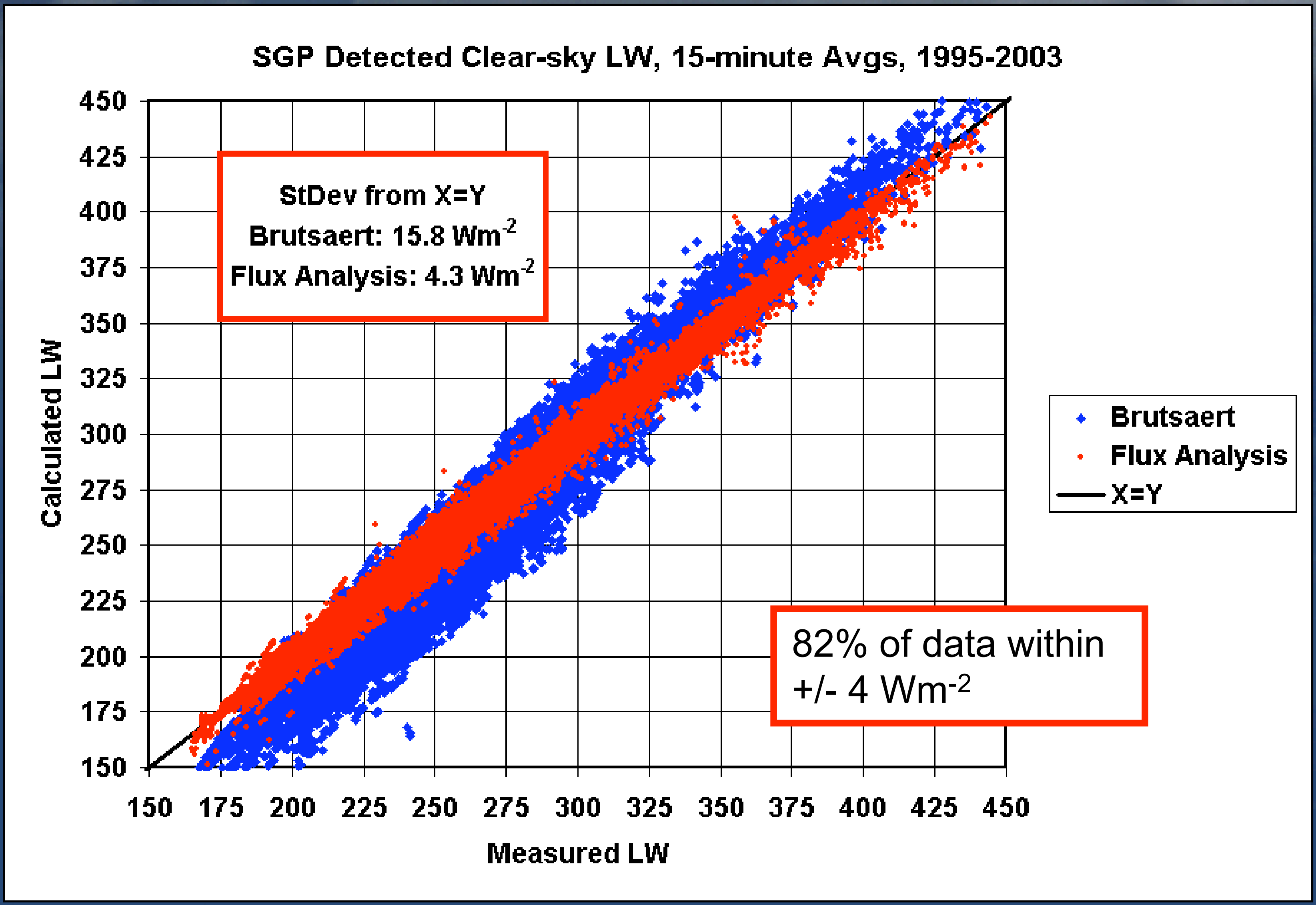
Clear-Sky Downwelling LW

- Effective clear (cloudless) sky downwelling LW
  - Related work by Marty and Philopona (2000), Duerr and Philipona (2004), Sutter at al. (2004)
  - Based on formulation proposed by Brutsaert (1975) using surface measurements of <u>air temperature and humidity</u>

Clear-Sky LW

- Our approach:
  - Use SWFA detected clear-sky periods
  - Additionally detect "LW effective clear-sky" periods
    - Variability of LW time series (after Marty and Philipona, 2000, GRL)
    - Use $T_a – T_e$ difference
    - If 21-minute running standard deviation < 0.7 Wm^{-2} and $(T_a\text{-}T_e)$ > 12 K, then data are labeled "LW clear-sky"
  - Use clear-sky measurements to calculate Brutsaert lapse rate coefficients
  - Interpolate coefficients for cloudy periods similar to SWFA (but must include sub-24-hour approach)

Estimated Clear-Sky LW



LW downwelling cloud effect and sky cover

- **Comparison of a continuous estimate of downwelling clear-sky LW to the LW measurements yields the cloud effect**
- **Durr and Philipona (2004, JGR)**
  - <u>Related</u> the variability of LW measurements
  - <u>And</u> ratio of the "effective LW emissivity" from measured LW ($\_{m}$) over the "effective clear-sky LW emissivity" ($\_{c}$)
  - <u>To</u> observer reports of low and mid-level cloud amounts.

LW effective sky cover

- Durr and Philipona (2004, JGR) use previous variability to "nowcast".
  - Thus climatological clear LW estimates
  - Use "tuned" threshold limits and variability to classify LW effective sky cover, estimated in oktas
- We use a running 21-minute standard deviation centered on the time of interest instead.
- Some "tuning" is needed to refine our methodology
  - ARM has just deployed an IR Sky Imager we can use as comparison data for this refinement

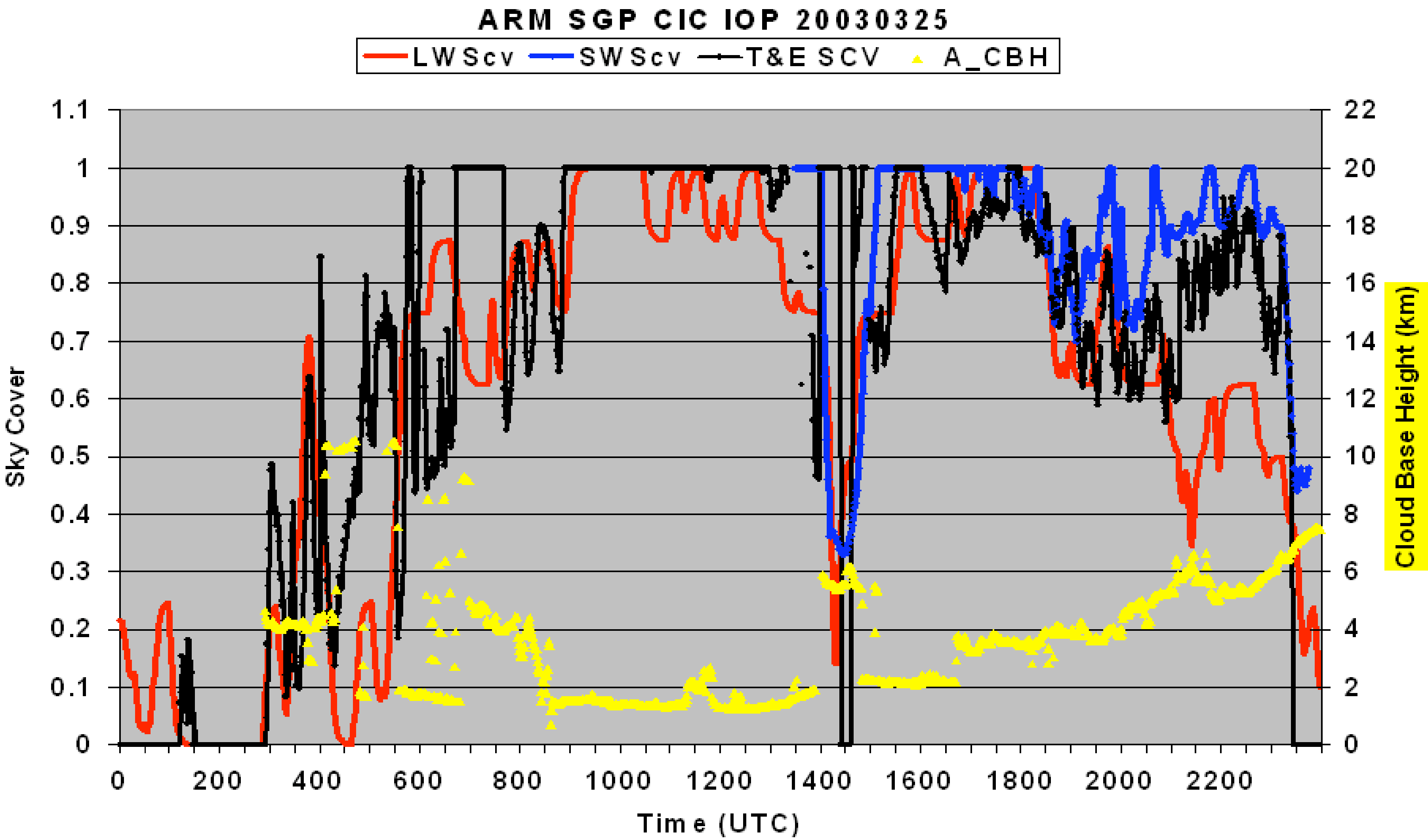
LW Scv: Alternate technique

- Han and Ellingson (1999) and Takara and Ellingson (2003) developed a technique to infer LW effective sky cover
- Uses spectral interferometer (AERI) measurements in the 8 – 12 micron infrared window
- Estimate both the clear-sky and overcast sky flux values
- Then use independent pixel approximation arguments and the measurements to estimate LW effective sky cover

Alternate technique (IRT)

- Flux Analysis provides the needed clear-sky and measured LW
- Use IRT measurements to infer cloudy sky radiating brightness temperature
- Use the Flux Analysis effective clear-sky LW emissivity and IRT to estimate the overcast LW influence on the LW measurement
- $SCV_{LW} = (LW - LW_{clr})/(LW_{ovc} – LW_{clr})$

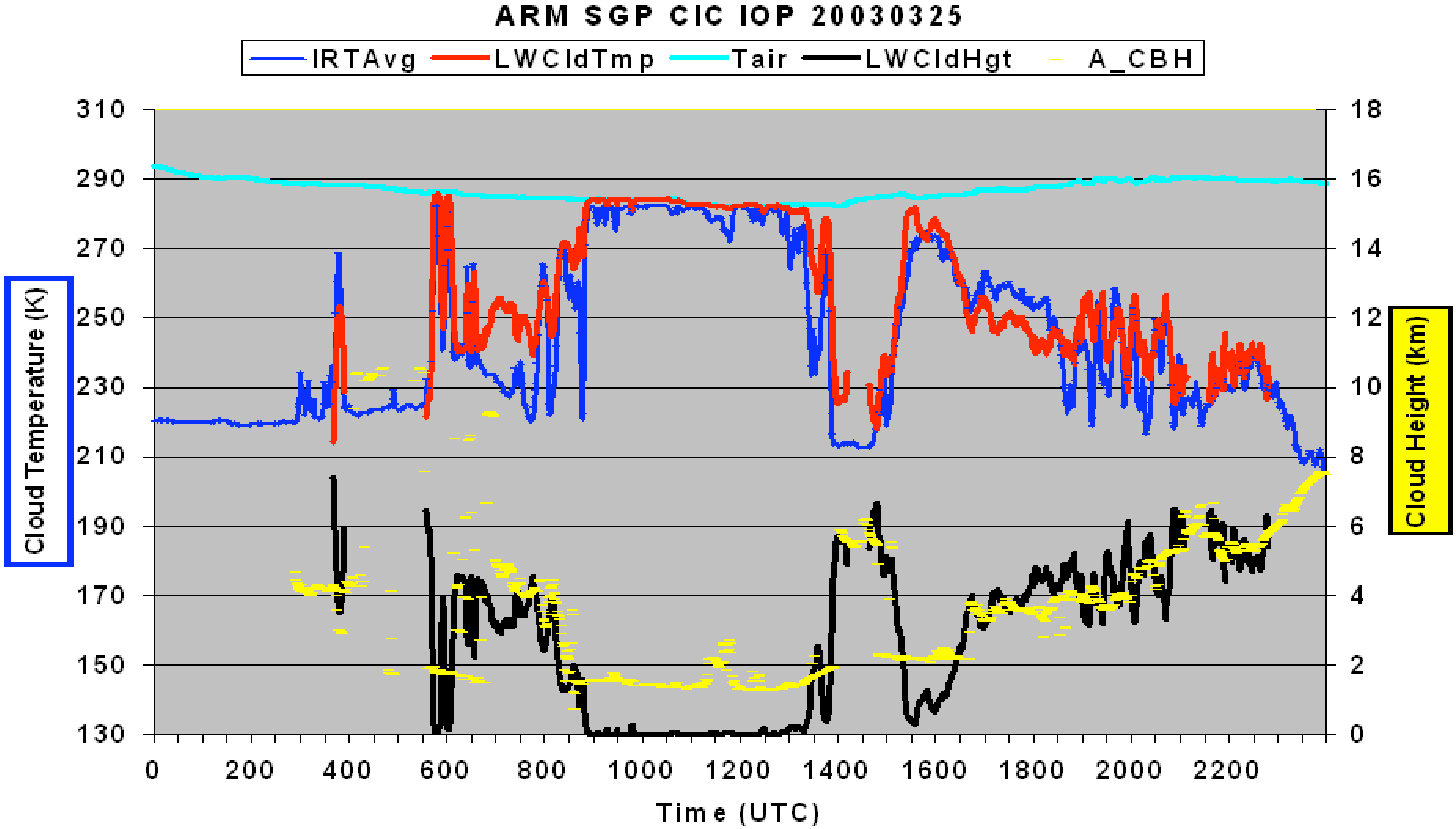
Estimated Sky Cover



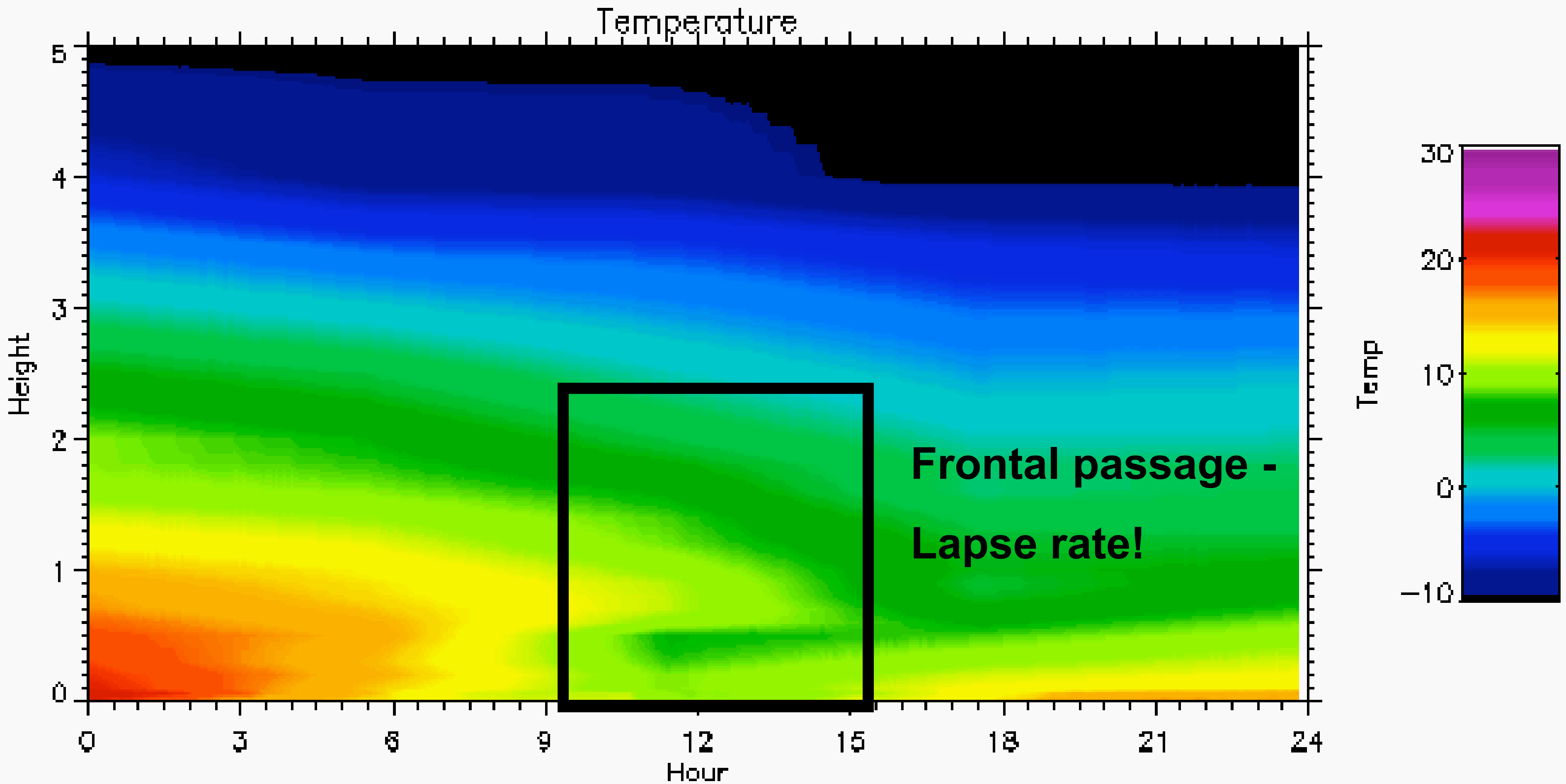
Cloud Temperature and Height

- If we have an IRT, we can infer cloud effective radiating temperature
- Alternatively, we can use independent pixel approximation arguments, the LW effective cloud amount, and the clear-sky and measured LW
  - $T_{cld} = \{(LW-LW_{clr})/([1-\_{c}]*SCV_{LW}*\_)\}^{1/4}$
  - Assumes single plane-parallel layer
- Use $T_a - T_{cld}$ difference, 10K/km lapse rate
- Results for low and middle clouds only

Cloud Temperature and Height



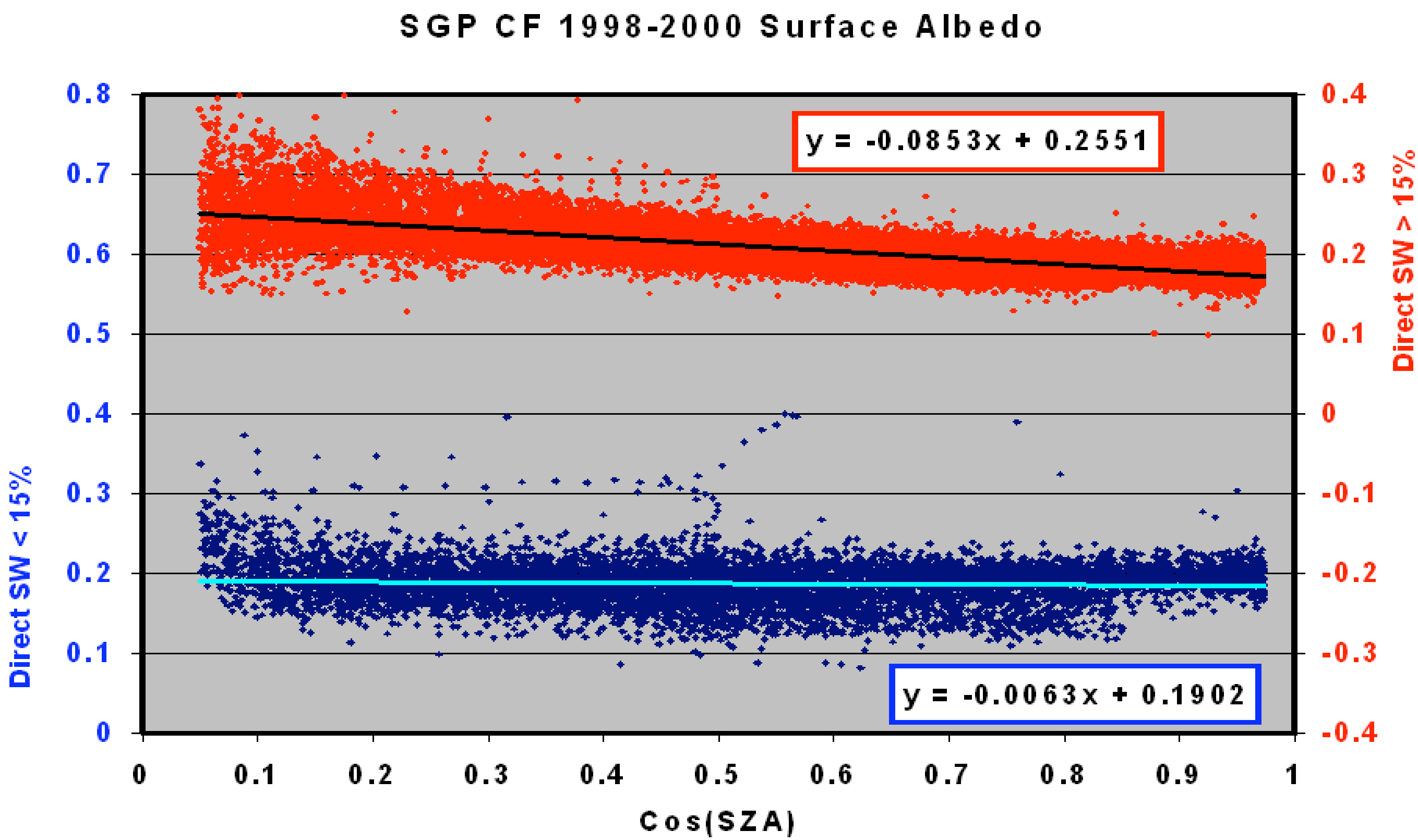
20030325 Raman Lidar



Clear-sky Upwelling SW

- Upwelling SW
  - Clear-sky fitting and interpolation
    - Misses surface changes occurring during cloudy periods [SNOW!]
  - Measured albedo times clear-sky SWdn
    - Albedo changes depending on whether direct component is blocked or not
  - Use climatological behavior of solar zenith angle dependence of "direct" albedo with running analysis of "diffuse" albedo

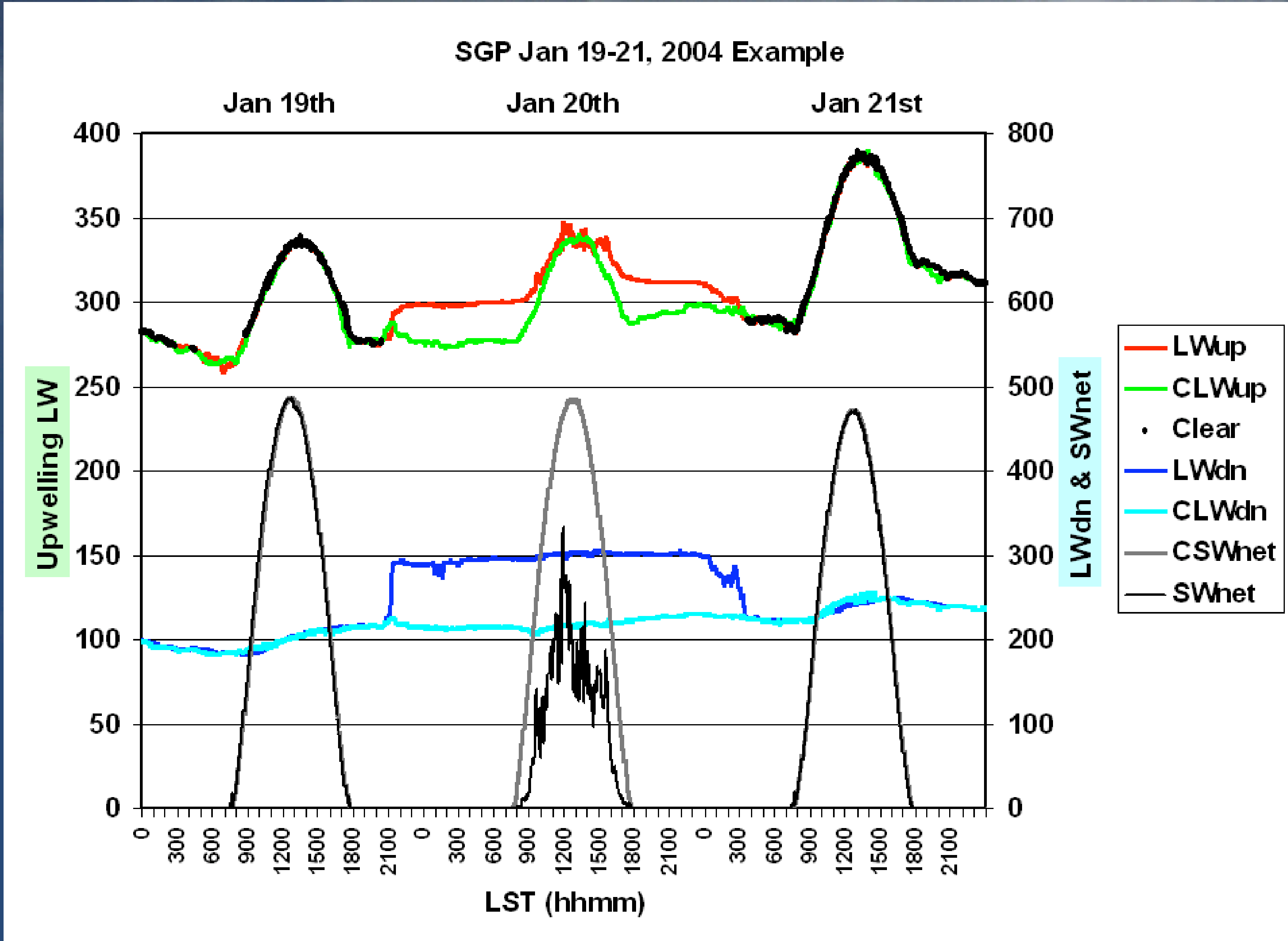
Surface Albedo Dependence



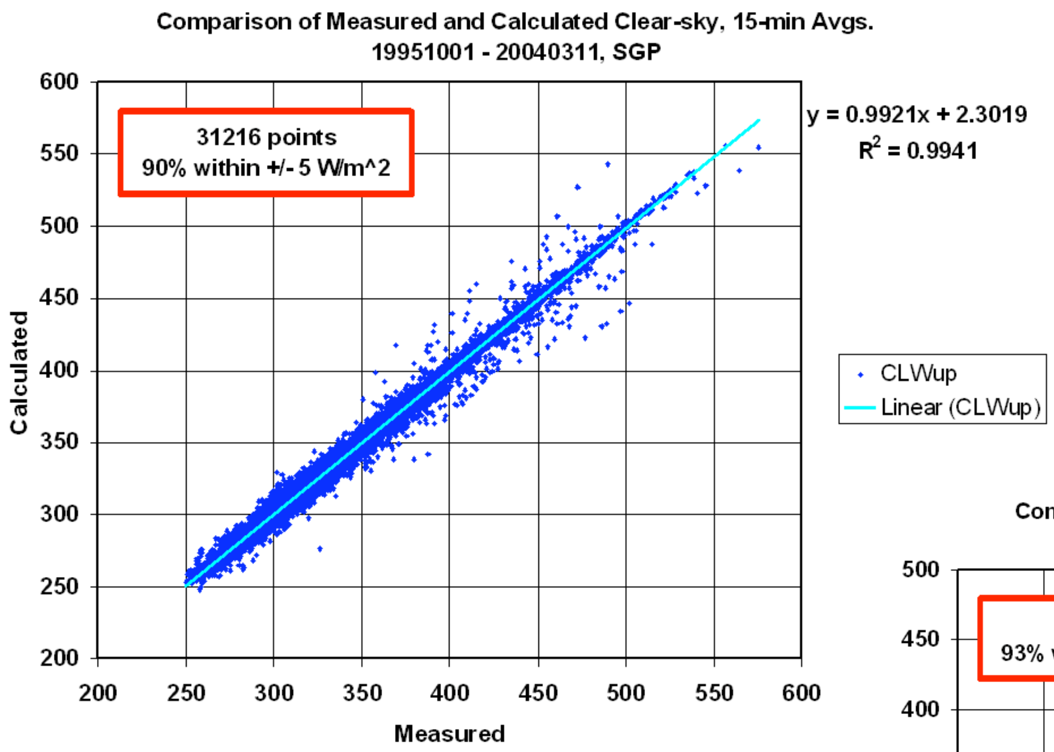
Clear-sky Upwelling LW

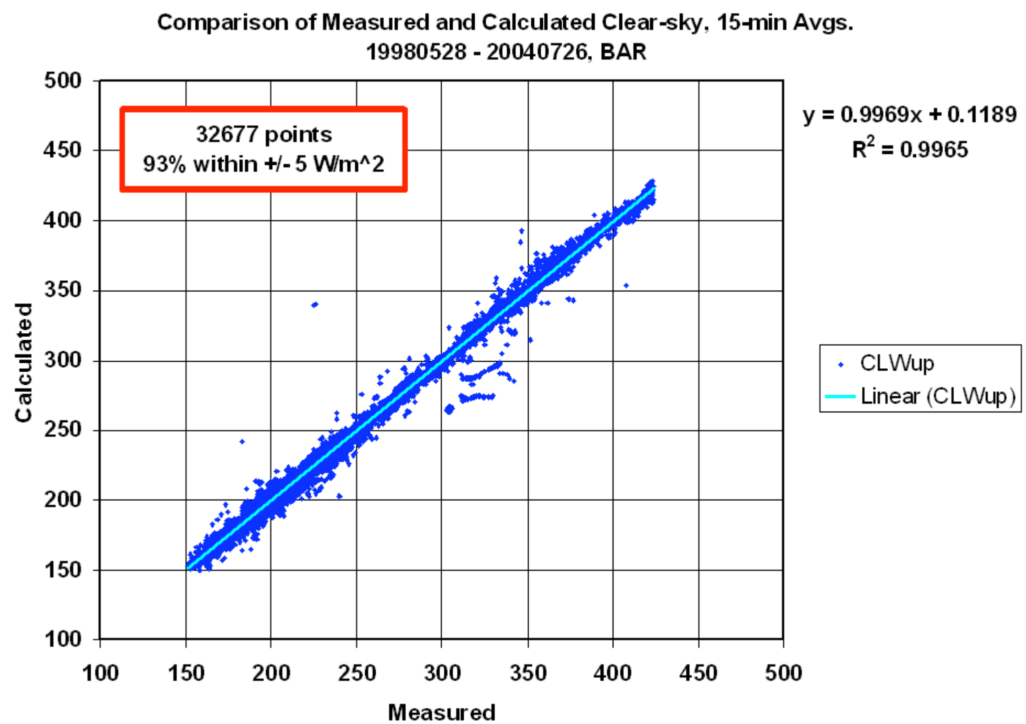
- Upwelling LW
  - Product of total surface energy exchange
    - Including latent and sensible heat
  - Multivariate fitting and interpolation
    - Using LWdn, SWnet, RH, Wspd
    - Primary driver is <u>LWdn</u>
      - LWdn related to LWup because emissivity = absorptivity
    - Some <u>SWnet</u> for vegetated surface converted to plant energy, not heat; not so for bare soil or snow
    - <u>RH & Wspd</u> surrogates for latent and sensible exchange
  - Difficult to verify for cloudy periods

LWup Example



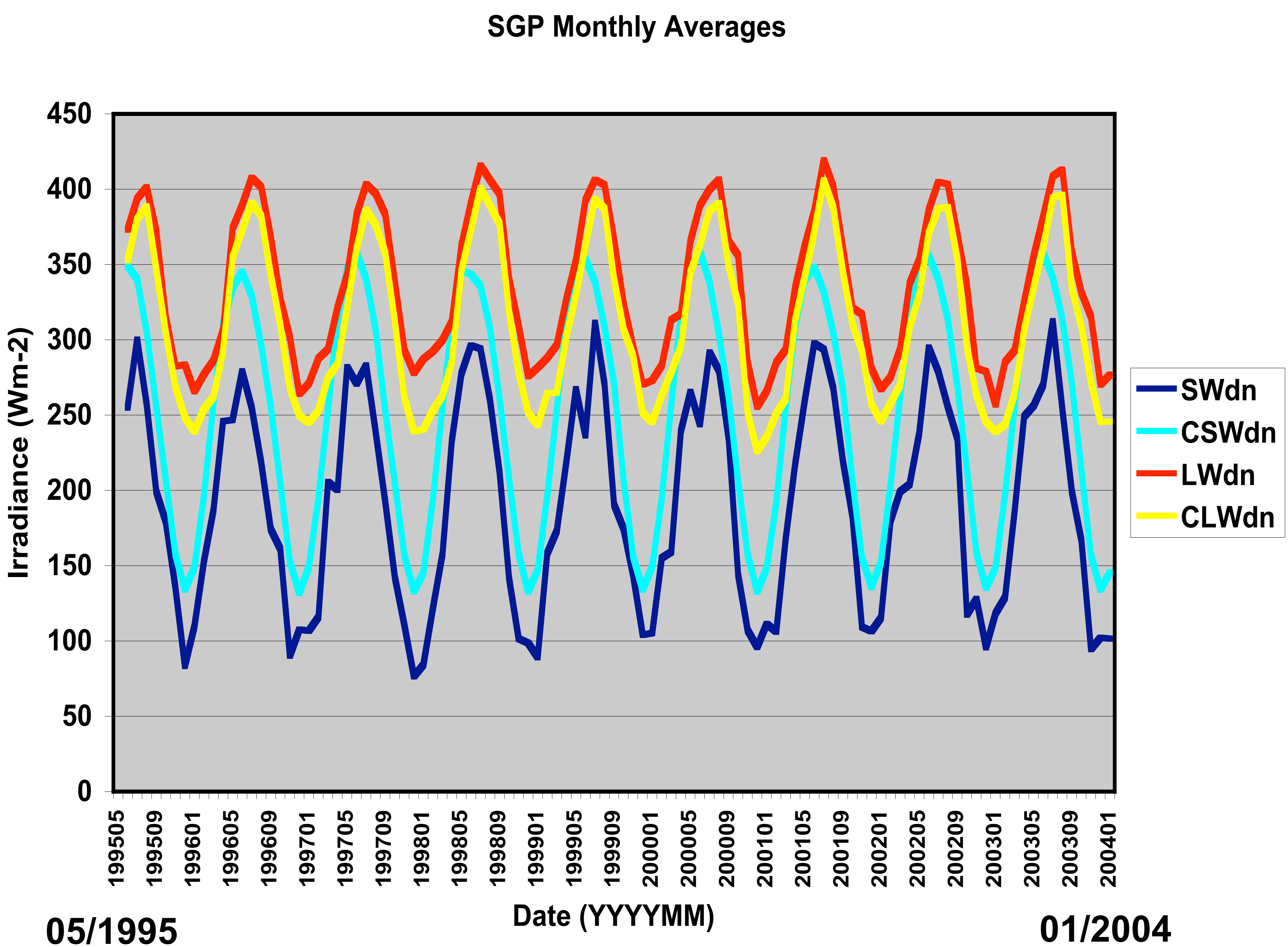
Estimated Clear-Sky LWup

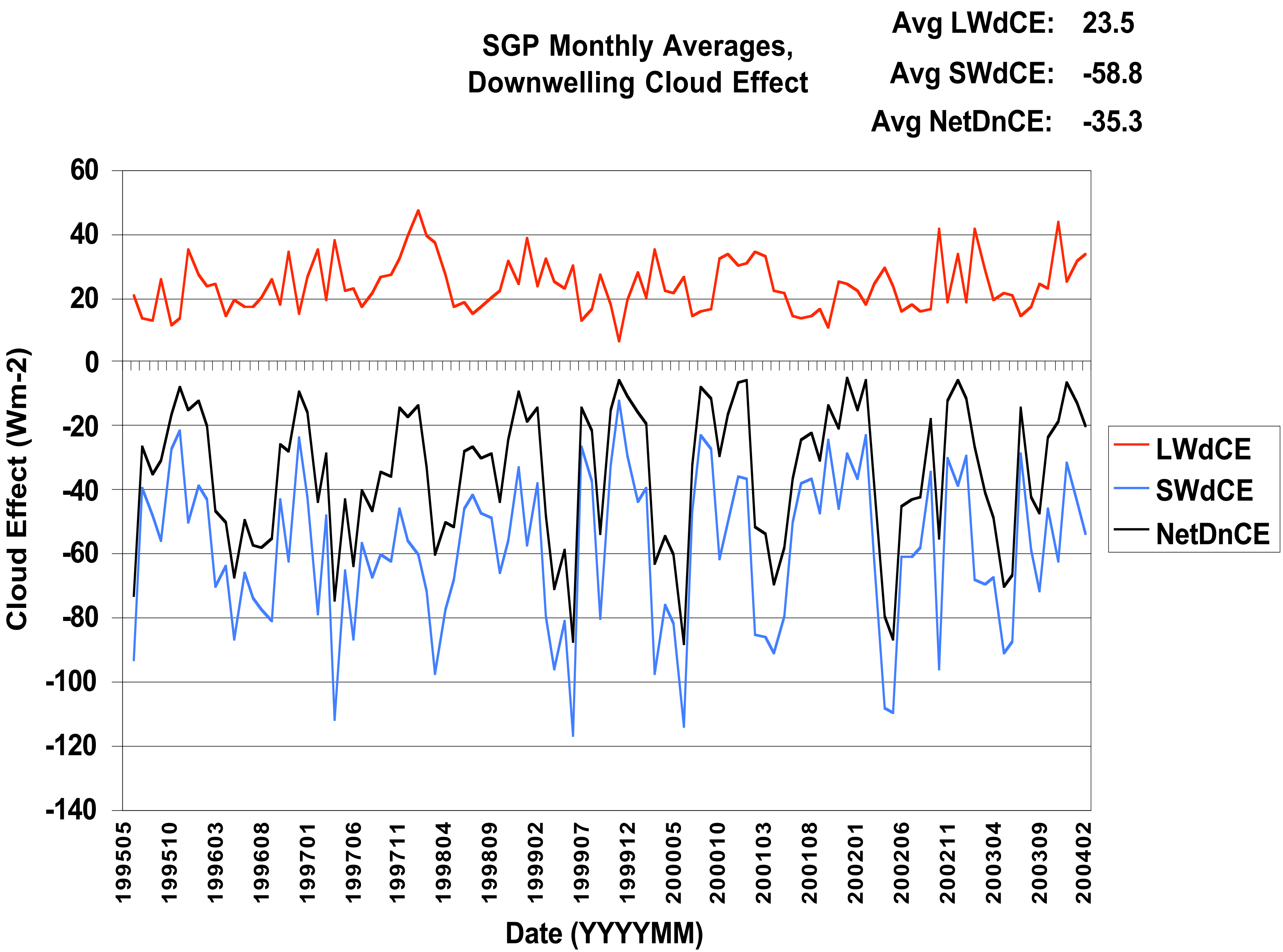


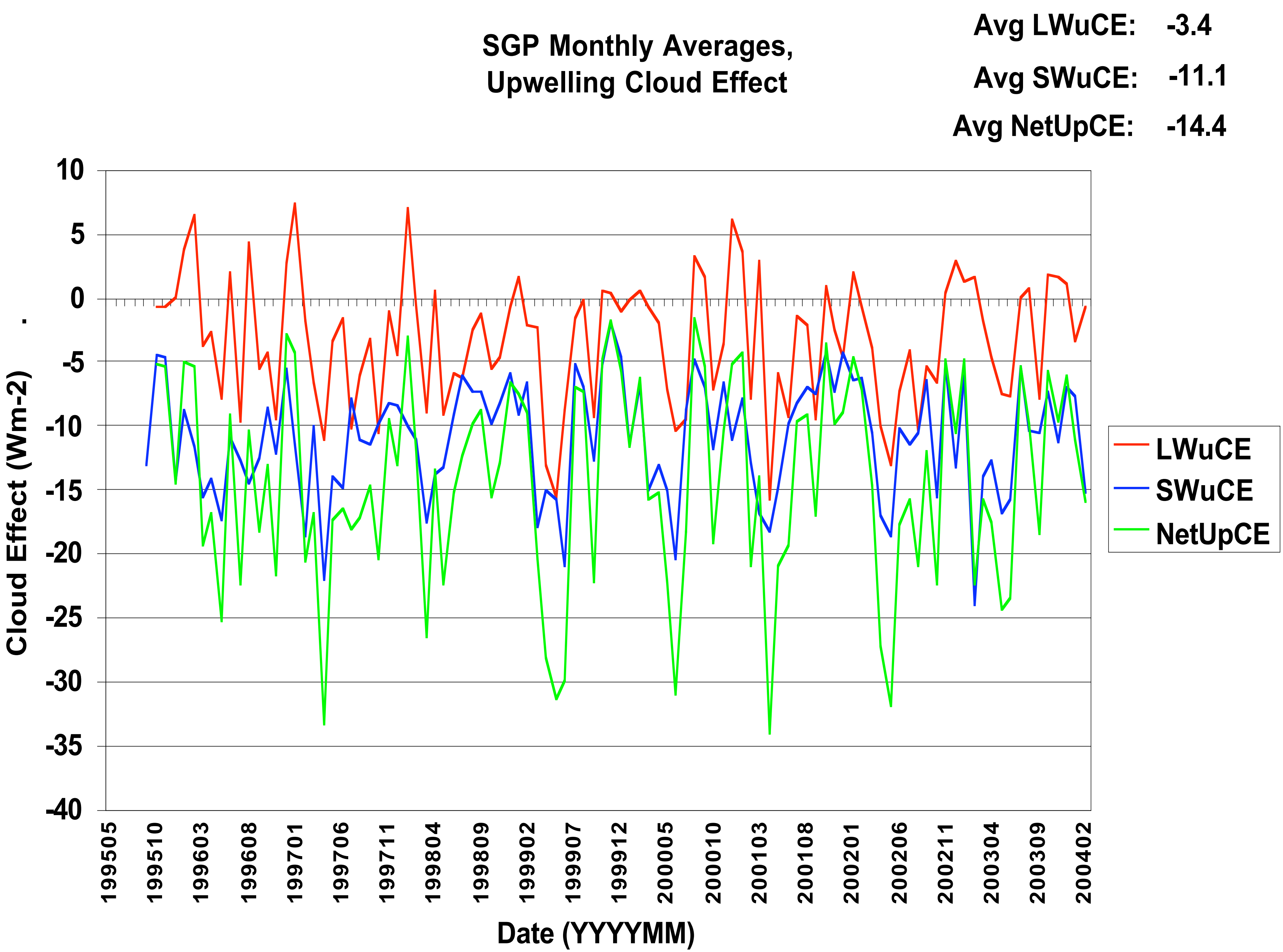


Example Analyses

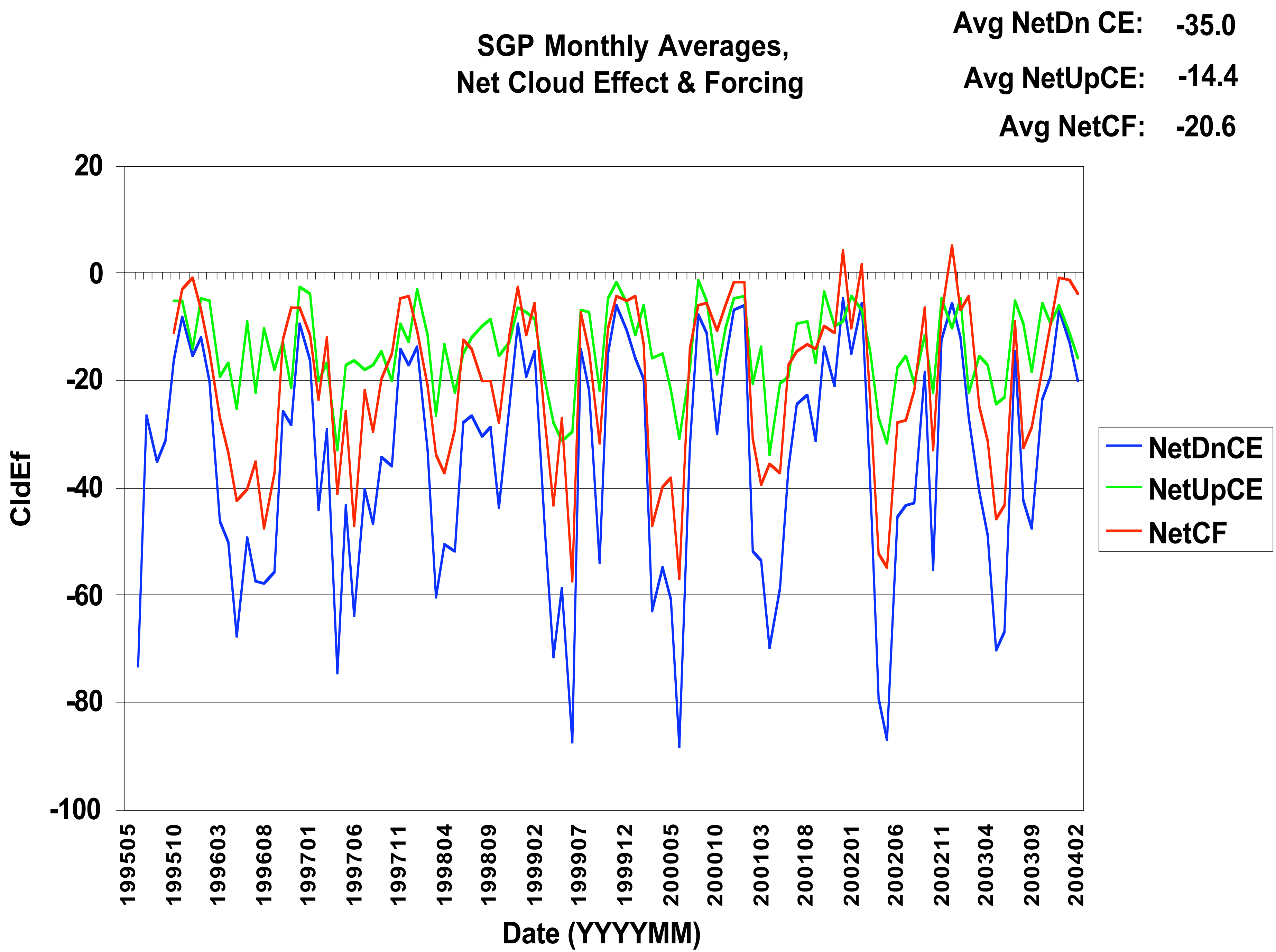
- The following are offered in the spirit of examples using the techniques described
  - Upwelling results are “work in progress”
- For these analyses, the clear-sky SWup was determined simply by taking the measured albedo times the clear-sky SWdn

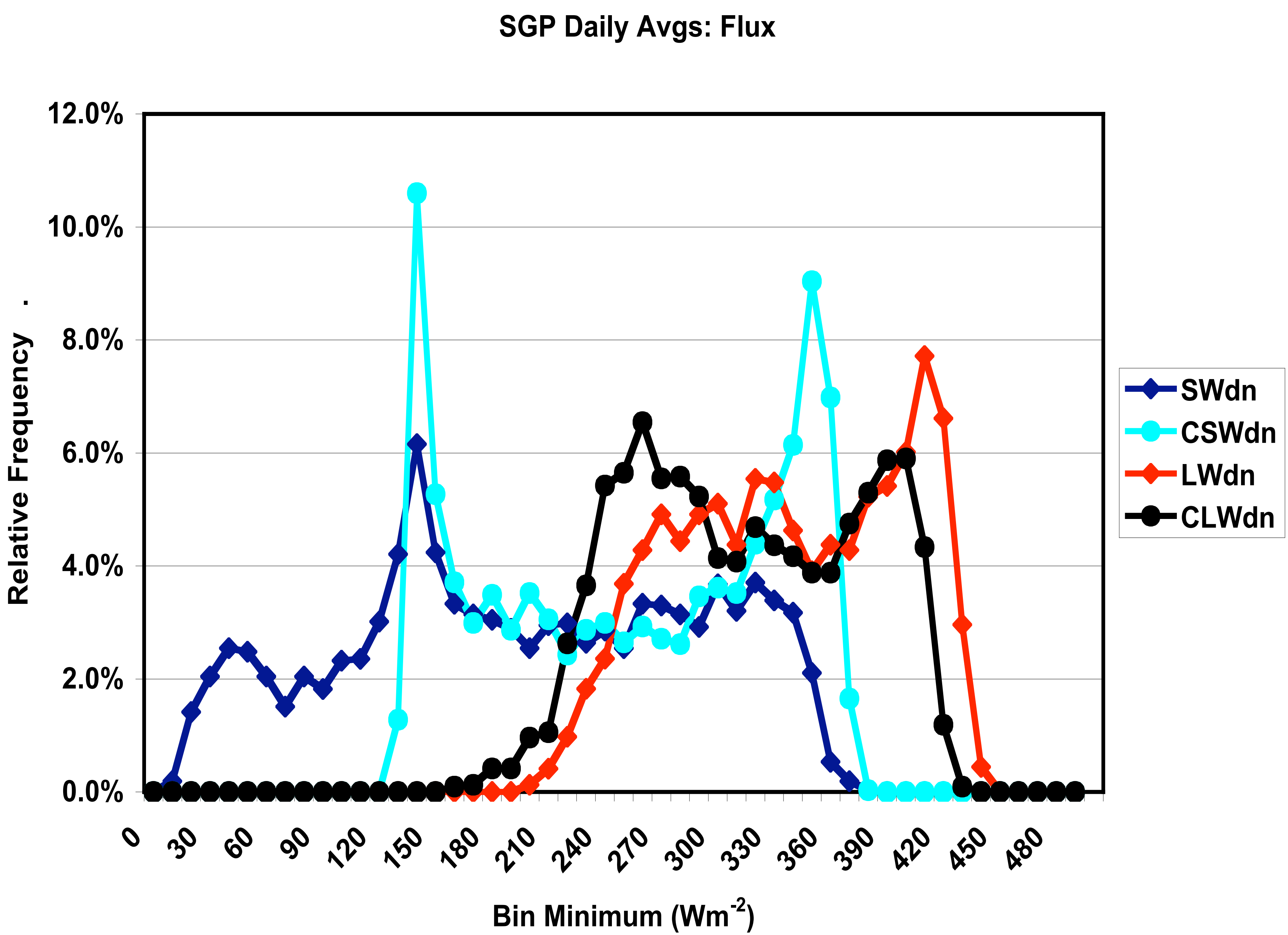

SGP Monthly Averages
Irradiance (Wm-2)
0
50
100
150
200
250
300
350
400
450
199505
199509
199601
199605
199609
199701
199705
199709
199801
199805
199809
199901
199905
199909
200001
200005
200009
200101
200105
200109
200201
200205
200209
200301
200305
200309
200401
Date (YYYYMM)
SWdn
CSWdn
LWdn
CLWdn
05/1995
01/2004

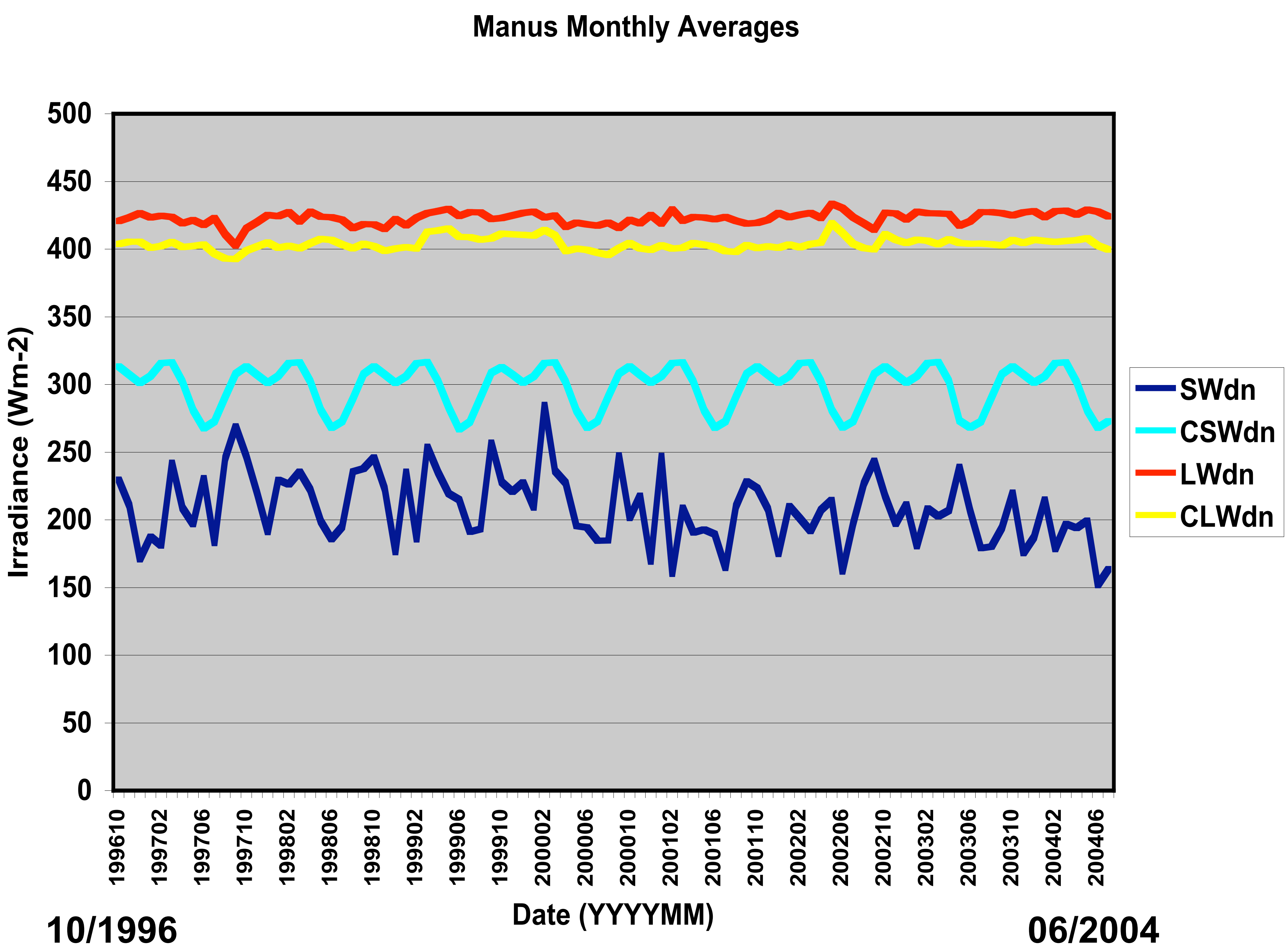

SGP Monthly Averages,
Downwelling Cloud Effect
Avg LWdCE: 23.5
Avg SWdCE: -58.8
Avg NetDnCE: -35.3
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
Cloud Effect (Wm-2)
LWdCE
SWdCE
NetDnCE
199505
199510
199603
199608
199701
199706
199711
199804
199809
199902
199907
199912
200005
200010
200103
200108
200201
200206
200211
200304
200309
200402
Date (YYYYMM)

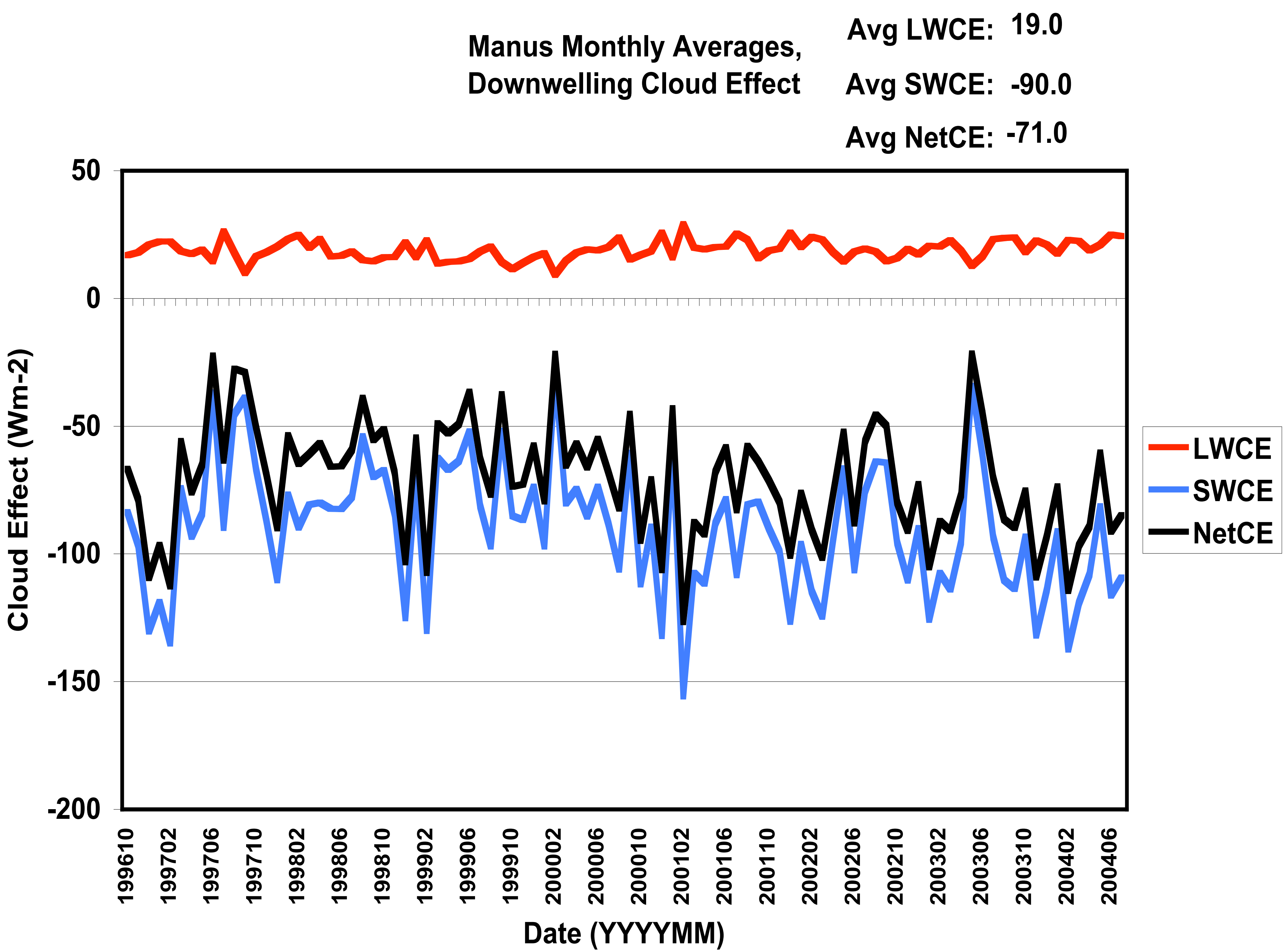


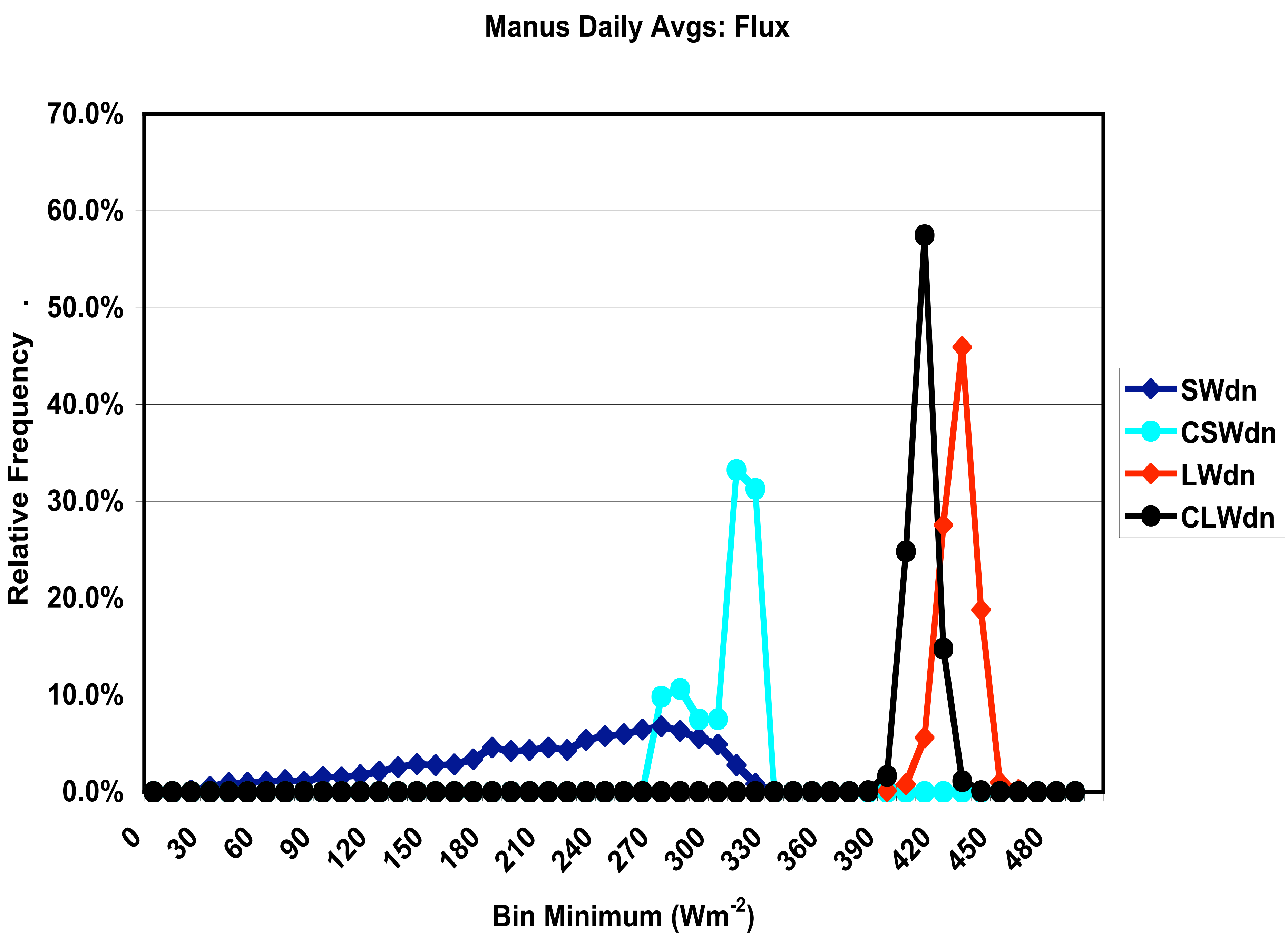
SGP Monthly Averages,
Upwelling Cloud Effect
Avg LWuCE: -3.4
Avg SWuCE: -11.1
Avg NetUpCE: -14.4
Cloud Effect (Wm-2)
Date (YYYYMM)
LWuCE
SWuCE
NetUpCE
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
199505
199510
199603
199608
199701
199706
199711
199804
199809
199902
199907
199912
200005
200010
200103
200108
200201
200206
200211
200304
200309
200402


SGP Monthly Averages,
Net Cloud Effect & Forcing
Avg NetDn CE: -35.0
Avg NetUpCE: -14.4
Avg NetCF: -20.6
20
0
-20
-40
-60
-80
-100
CldEf
NetDnCE
NetUpCE
NetCF
199505
199510
199603
199608
199701
199706
199711
199804
199809
199902
199907
199912
200005
200010
200103
200108
200201
200206
200211
200304
200309
200402
Date (YYYYMM)

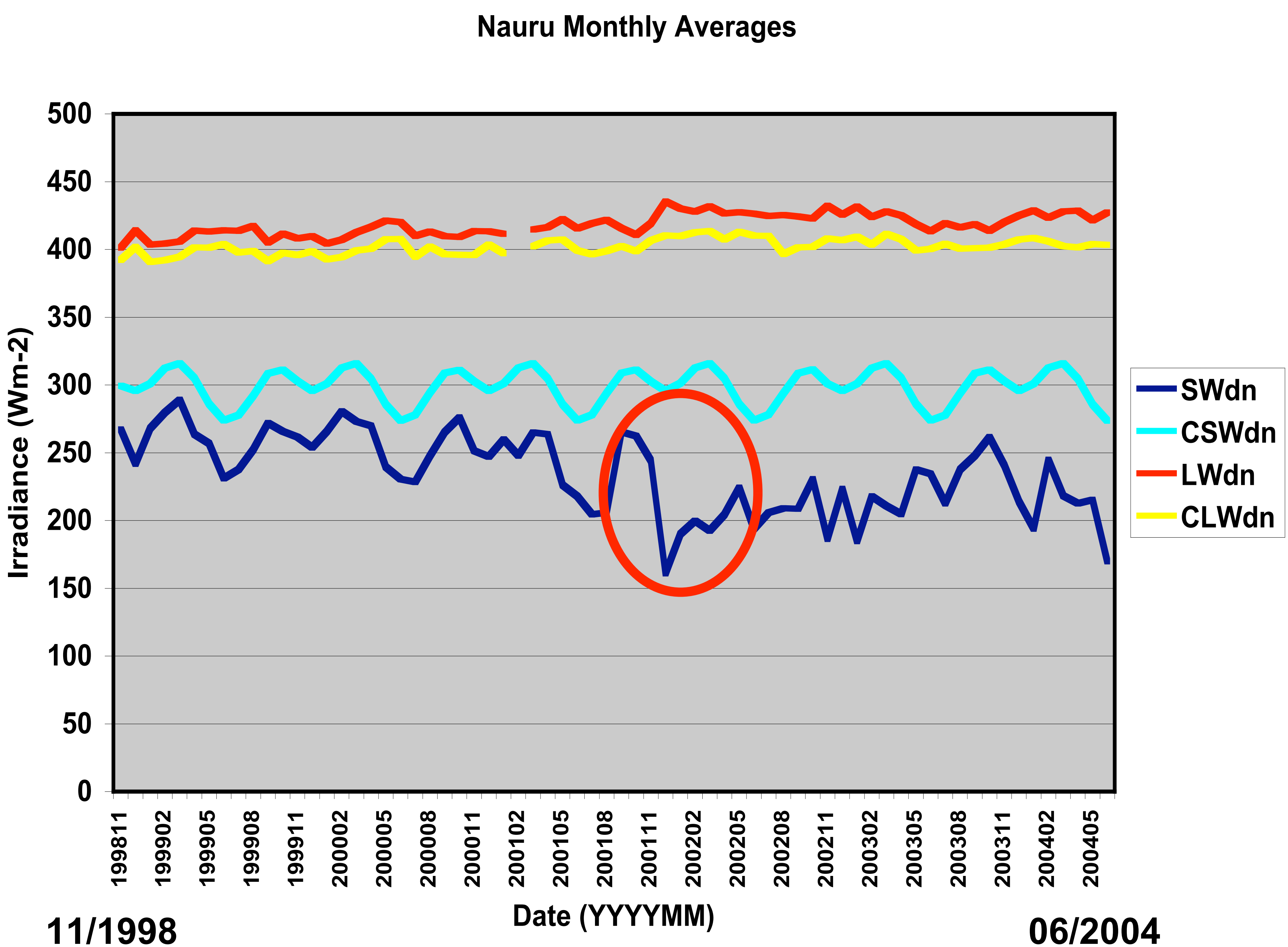

SGP Daily Avgs: Flux
Relative Frequency
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
Bin Minimum (Wm-2)
SWdn
CSWdn
LWdn
CLWdn

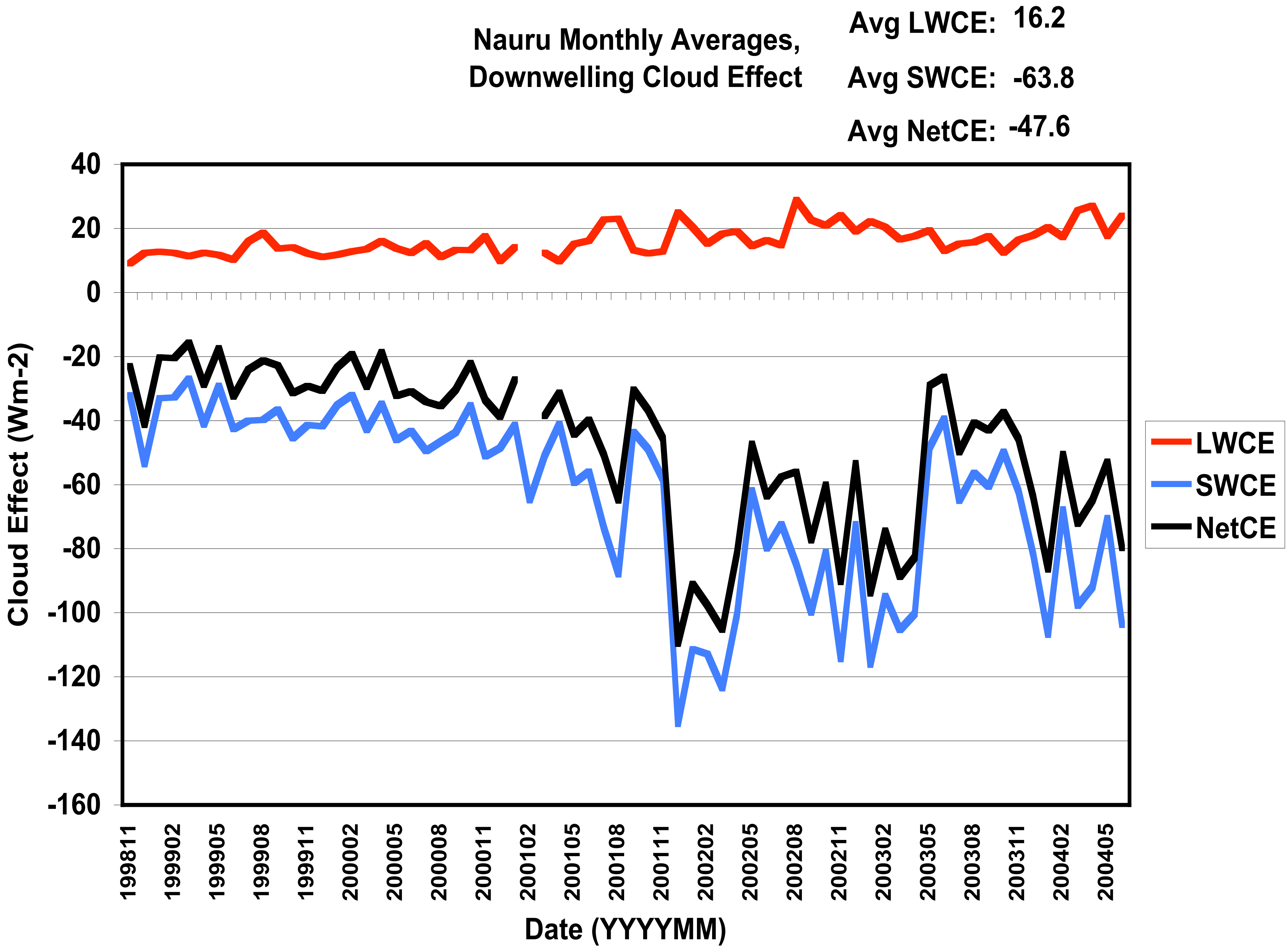

Manus Monthly Averages
Irradiance (Wm-2)
500
450
400
350
300
250
200
150
100
50
0
199610
199702
199706
199710
199802
199806
199810
199902
199906
199910
200002
200006
200010
200102
200106
200110
200202
200206
200210
200302
200306
200310
200402
200406
Date (YYYYMM)
SWdn
CSWdn
LWdn
CLWdn
10/1996
06/2004


Manus Monthly Averages,
Downwelling Cloud Effect
Avg LWCE: 19.0
Avg SWCE: -90.0
Avg NetCE: -71.0
Cloud Effect (Wm-2)
50
0
-50
-100
-150
-200
LWCE
SWCE
NetCE
199610
199702
199706
199710
199802
199806
199810
199902
199906
199910
200002
200006
200010
200102
200106
200110
200202
200206
200210
200302
200306
200310
200402
200406
Date (YYYYMM)

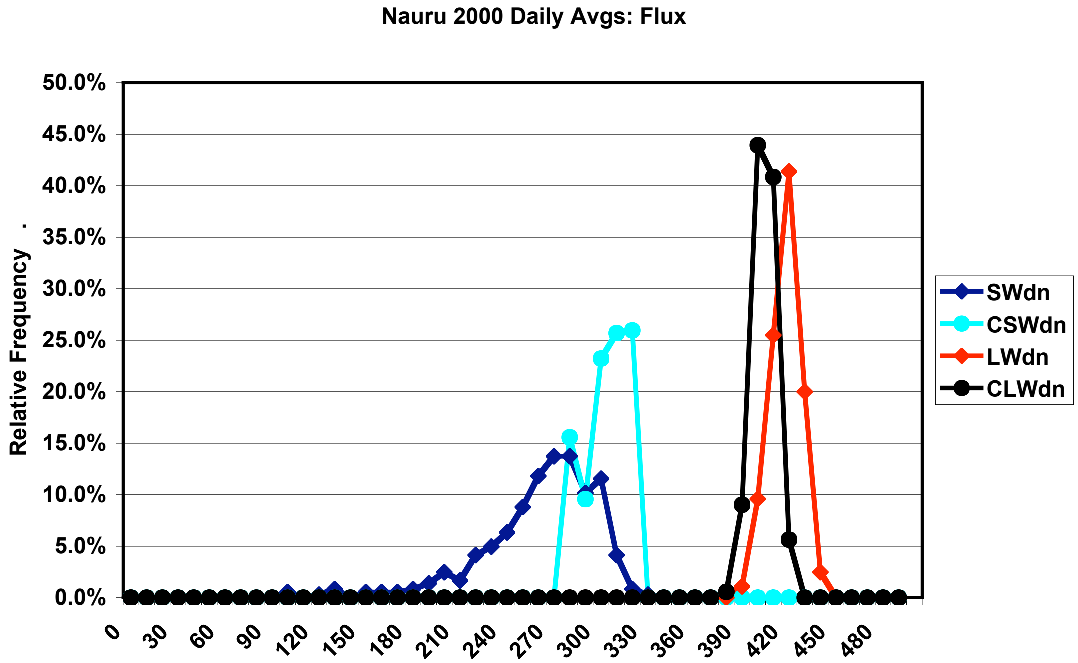


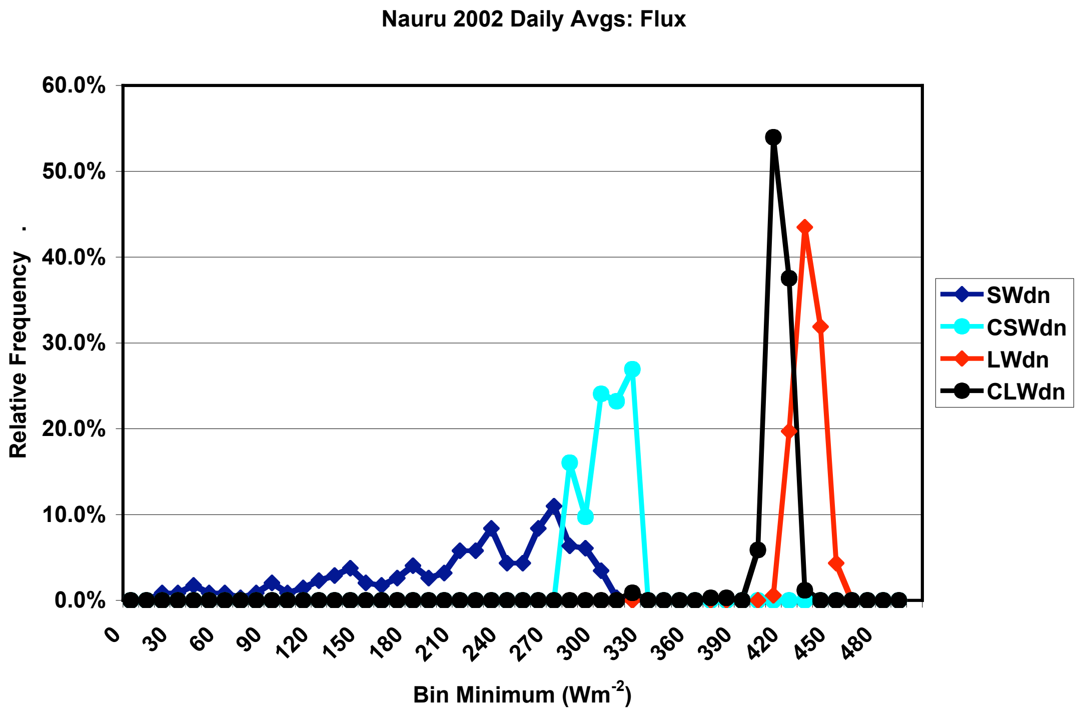
Manus Daily Avgs: Flux
Relative Frequency
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
Bin Minimum (Wm-2)
SWdn
CSWdn
LWdn
CLWdn


Nauru Monthly Averages
Irradiance (Wm-2)
500
450
400
350
300
250
200
150
100
50
0
199811
199902
199905
199908
199911
200002
200005
200008
200011
200102
200105
200108
200111
200202
200205
200208
200211
200302
200305
200308
200311
200402
200405
Date (YYYYMM)
SWdn
CSWdn
LWdn
CLWdn
11/1998
06/2004



Nauru Monthly Averages,
Downwelling Cloud Effect
Avg LWCE: 16.2
Avg SWCE: -63.8
Avg NetCE: -47.6
Cloud Effect (Wm-2)
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
LWCE
SWCE
NetCE
199811
199902
199905
199908
199911
200002
200005
200008
200011
200102
200105
200108
200111
200202
200205
200208
200211
200302
200305
200308
200311
200402
200405
Date (YYYYMM)



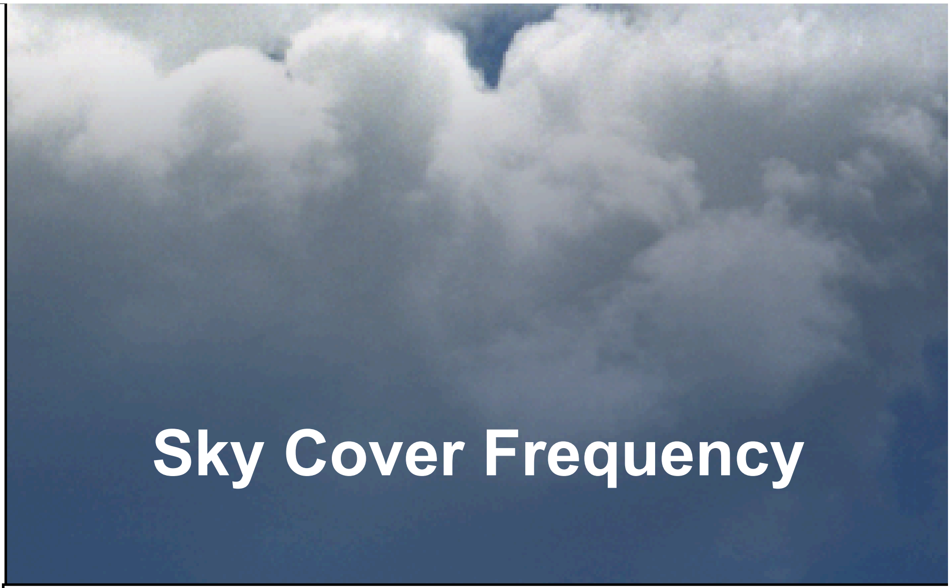


Nauru – 2000

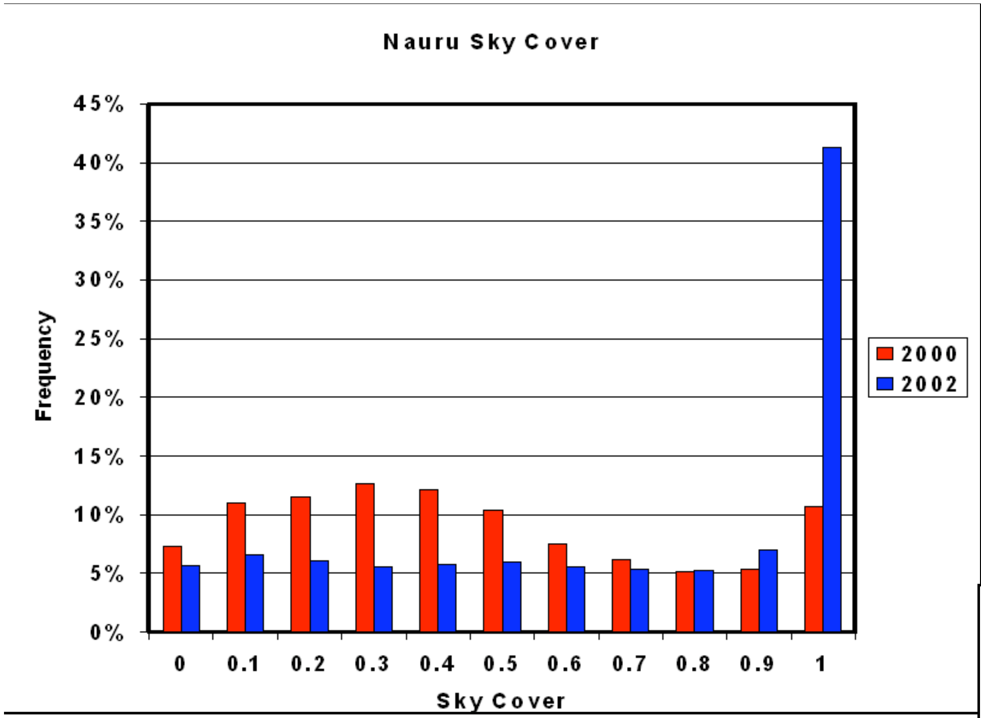
La Nina phase (suppressed)

Nauru – 2002

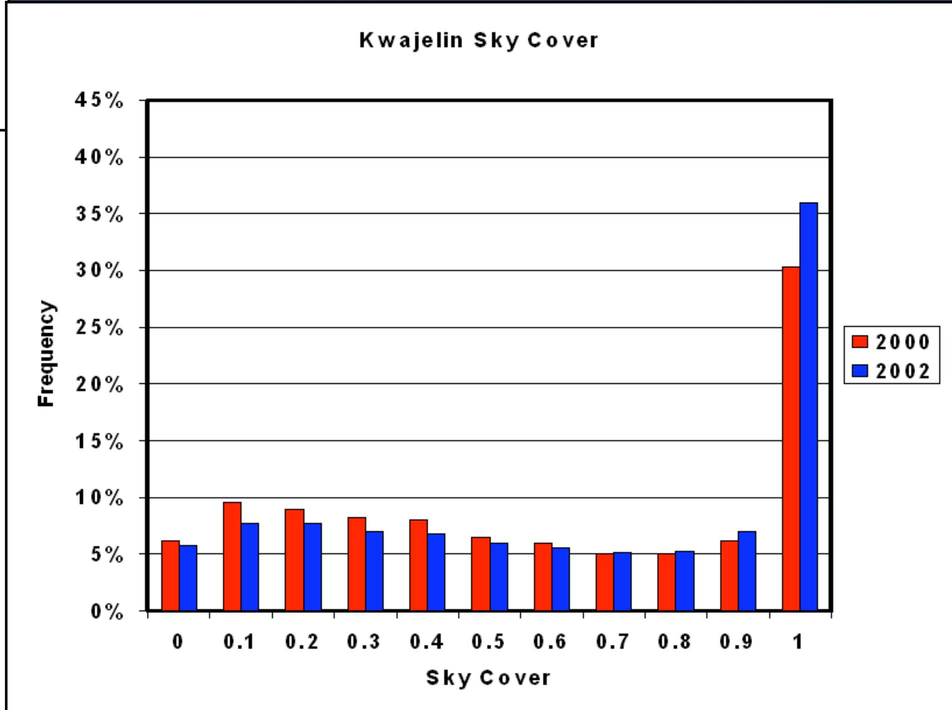
El Nino phase (convective)



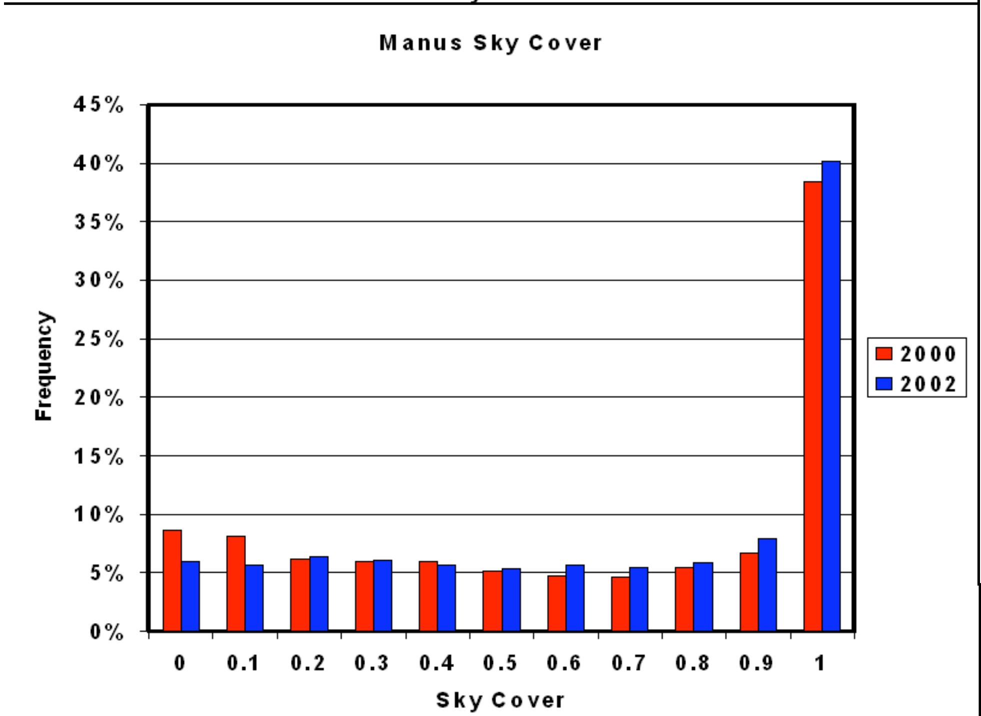
Sky Cover Frequency



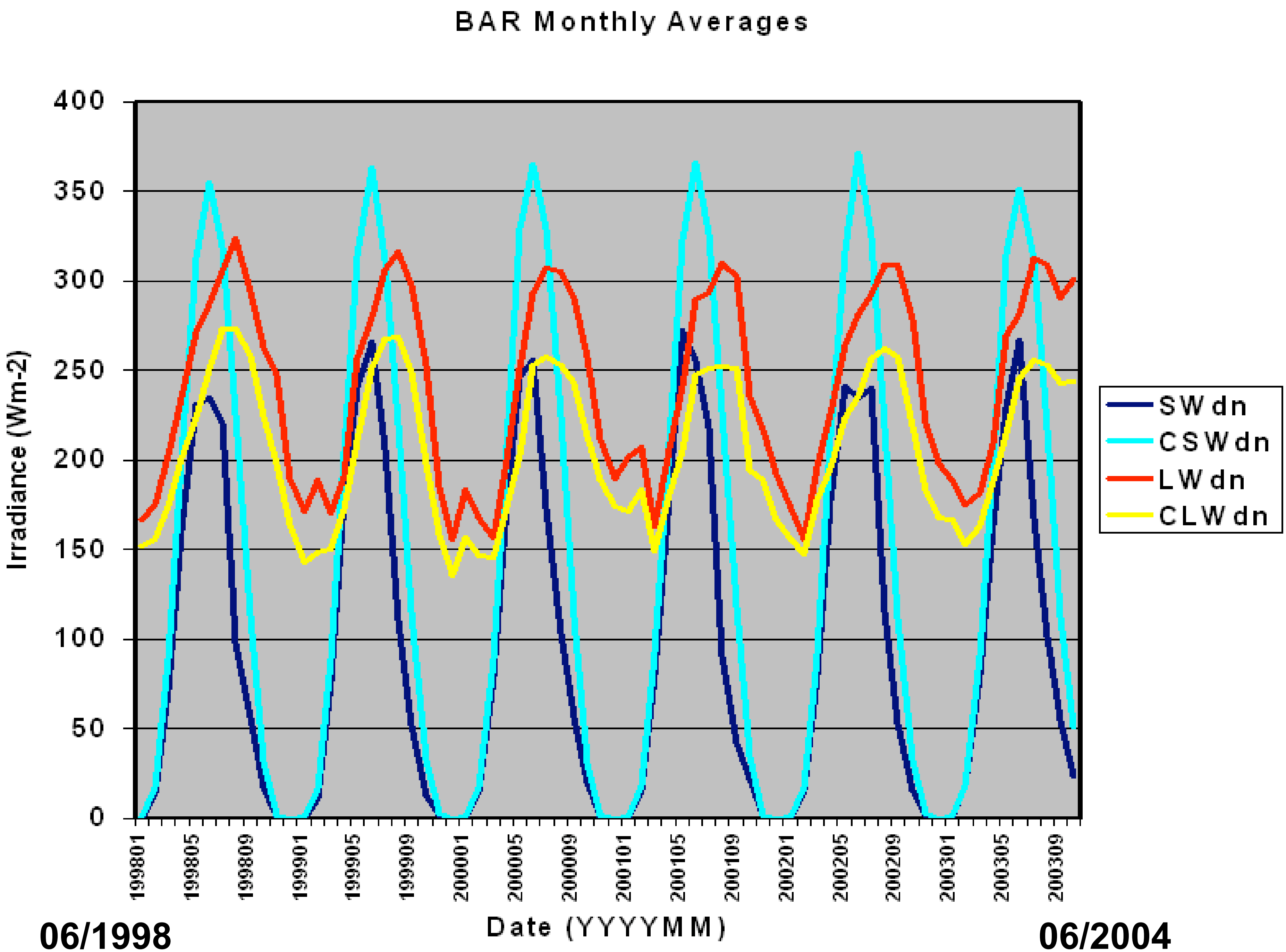
Nauru Sky Cover
Frequency
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Sky Cover
2000
2002



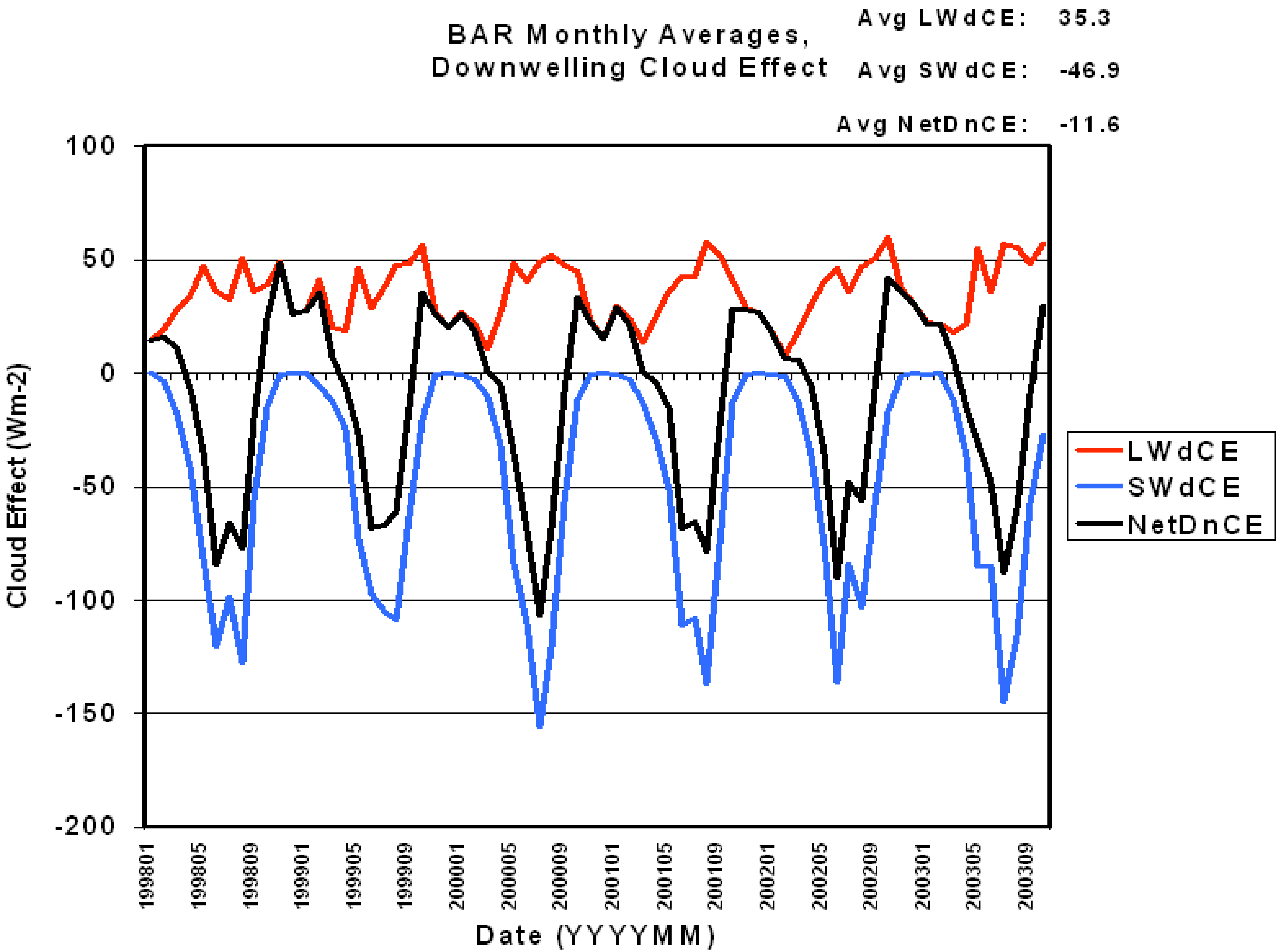
Kwajelin Sky Cover
Frequency
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Sky Cover
2000
2002



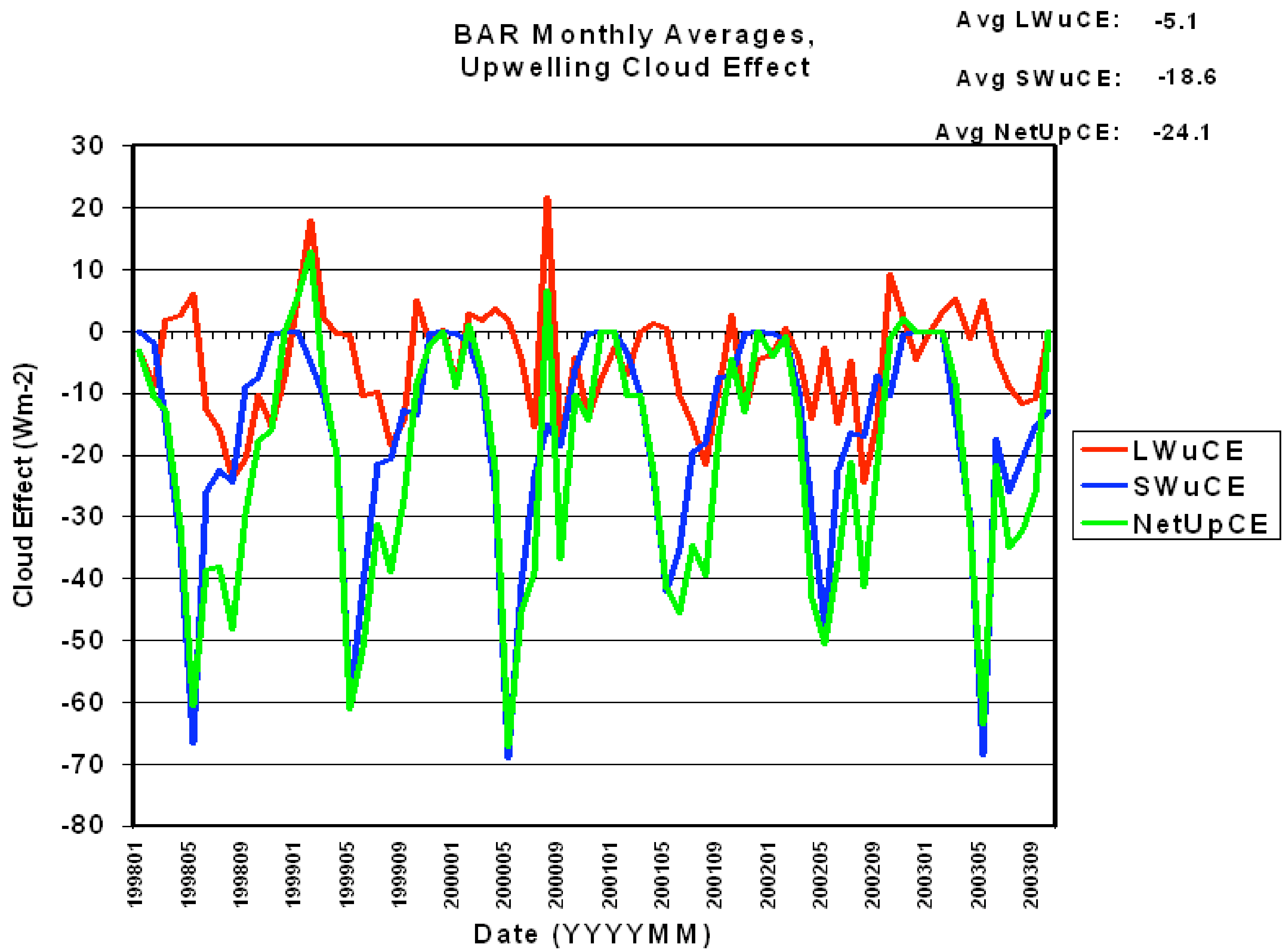
Manus Sky Cover
Frequency
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Sky Cover
2000
2002

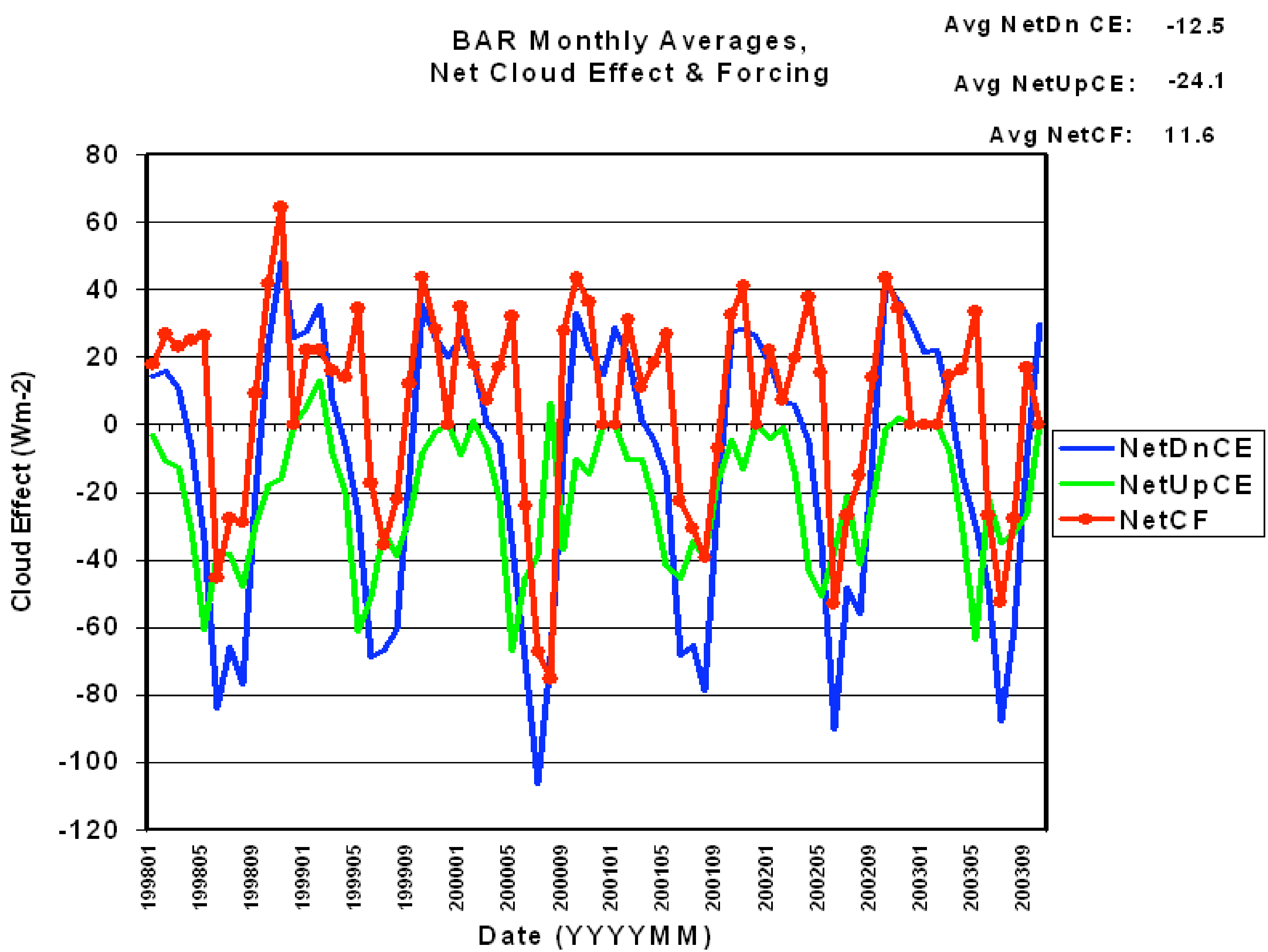


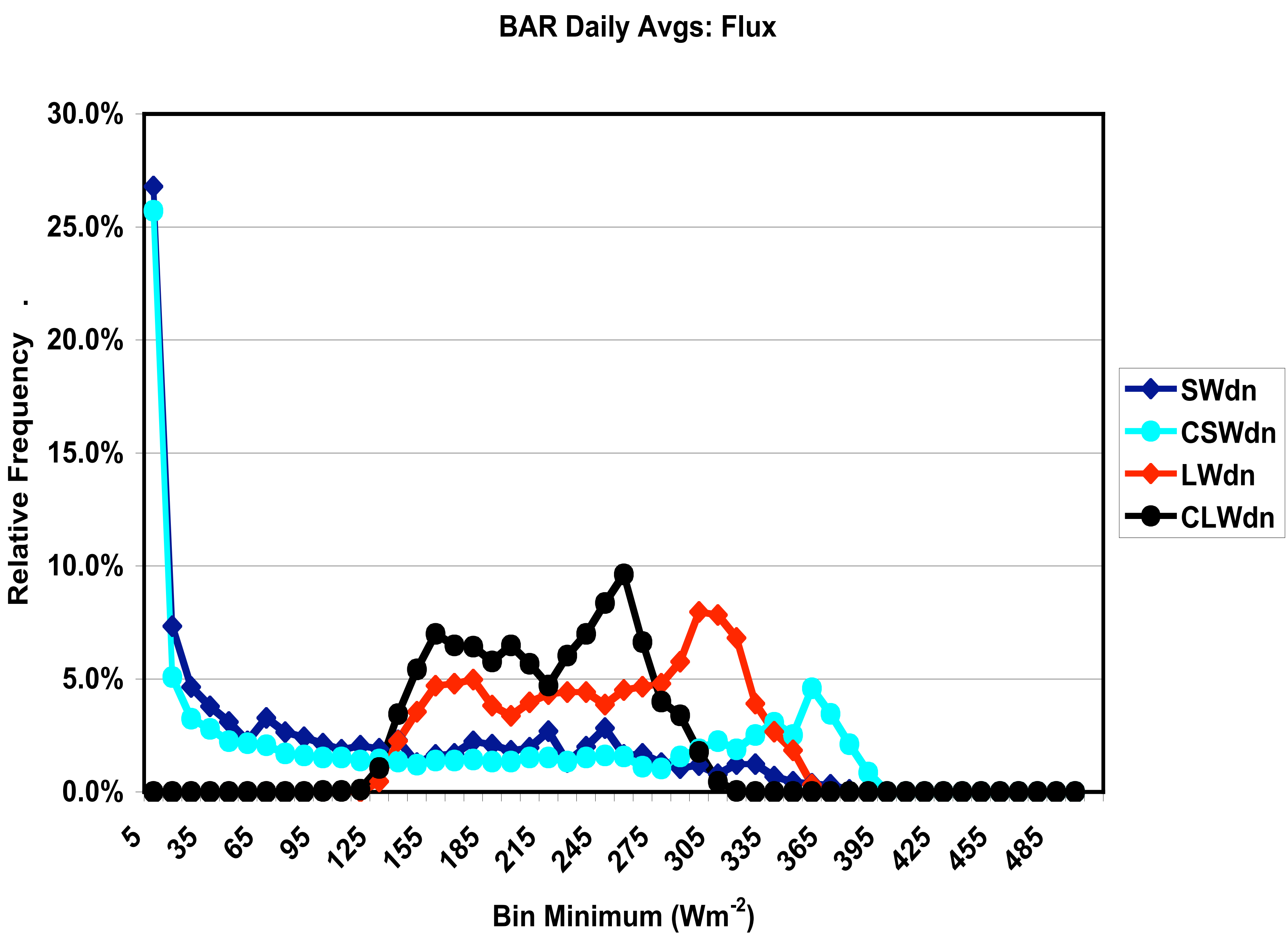
06/1998 **06/2004**



BAR Monthly Averages,
Downwelling Cloud Effect
Avg LWdCE: 35.3
Avg SWdCE: -46.9
Avg NetDnCE: -11.6
100
50
0
-50
-100
-150
-200
Cloud Effect (Wm-2)
199801
199805
199809
199901
199905
199909
200001
200005
200009
200101
200105
200109
200201
200205
200209
200301
200305
200309
Date (YYYYMM)
LWdCE
SWdCE
NetDnCE


BAR Monthly Averages,
Upwelling Cloud Effect
Avg LWuCE: -5.1
Avg SWuCE: -18.6
Avg NetUpCE: -24.1
Cloud Effect (Wm-2)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
199801
199805
199809
199901
199905
199909
200001
200005
200009
200101
200105
200109
200201
200205
200209
200301
200305
200309
Date (YYYYMM)
LWuCE
SWuCE
NetUpCE


BAR Monthly Averages,
Net Cloud Effect & Forcing
Avg NetDn CE: -12.5
Avg NetUpCE: -24.1
Avg NetCF: 11.6
80
60
40
20
0
-20
-40
-60
-80
-100
-120
Cloud Effect (Wm-2)
NetDnCE
NetUpCE
NetCF
199801
199805
199809
199901
199905
199909
200001
200005
200009
200101
200105
200109
200201
200205
200209
200301
200305
200309
Date (YYYYMM)



BAR Daily Avgs: Flux
Relative Frequency
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
5
35
65
95
125
155
185
215
245
275
305
335
365
395
425
455
485
Bin Minimum (Wm-2)
SWdn
CSWdn
LWdn
CLWdn

Summary

- We can now infer useful cloud information using surface radiation and meteorological measurements
  - Clear-sky SW and LW, for cloud effect/forcing
  - SW and LW fractional sky cover
  - Cloud visible optical depths
  - Cloud field effective radiating temperature
  - Cloud field effective height
- This methodology uses no ancillary data (sondes, radar, RUC, etc.),
- Thus non-incestuous comparisons

Summary

- It is recommended that “basic” surface sites include:
  - – Broadband up and down SW and LW irradiances
  - – SW component (direct and diffuse)
  - – Surface meteorology (T, RH, Prs, Wspd, Wdir)
  - – NFOV IRT measurements

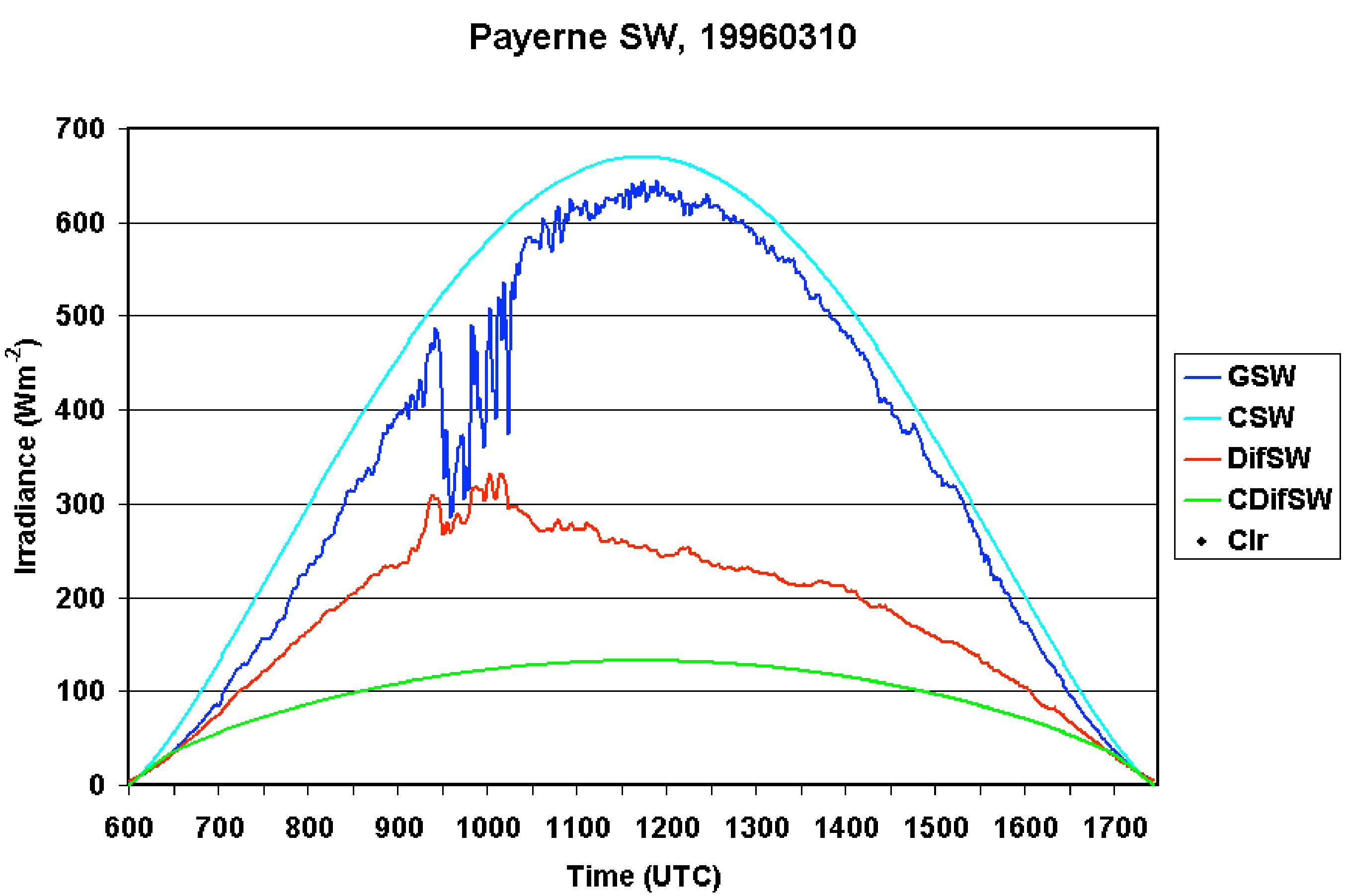
Collaborations

- I am seeking collaborations for analyses of BSRN-style surface radiation and met measurements
  - Centre for Broadband Cloud Retrievals
- For more information and correspondence:
- Chuck.Long@arm.gov

Thank You

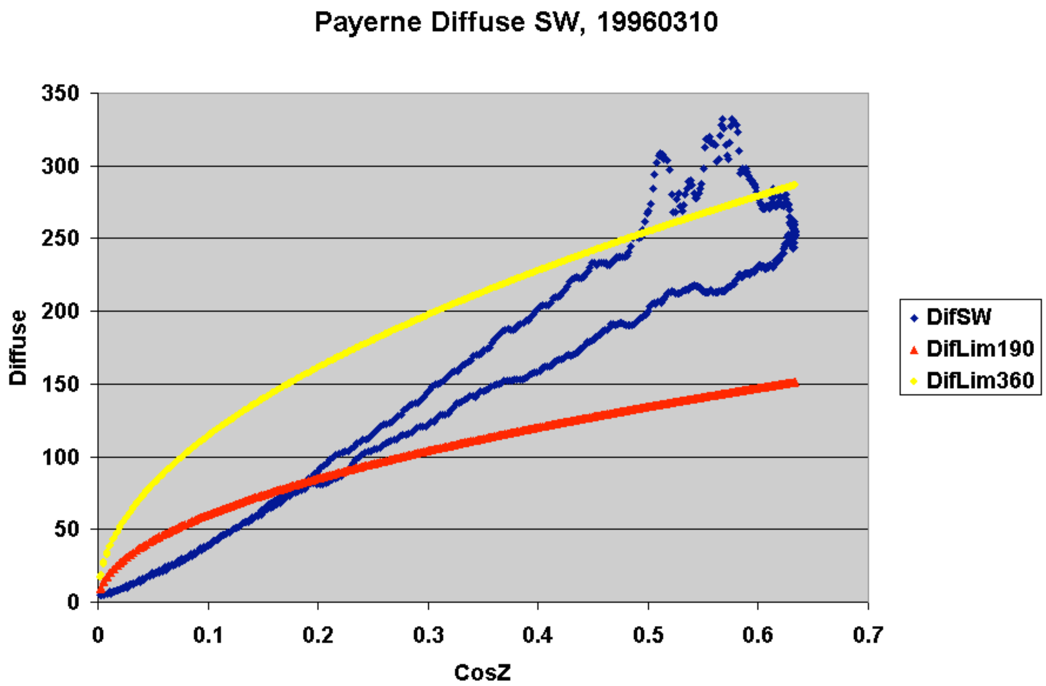
Questions?

"Cloudless" example

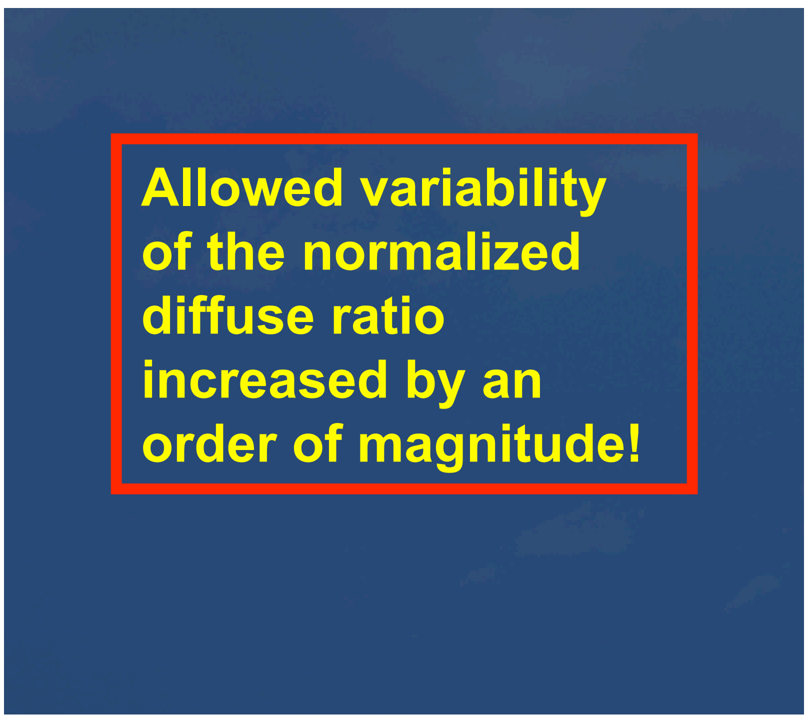


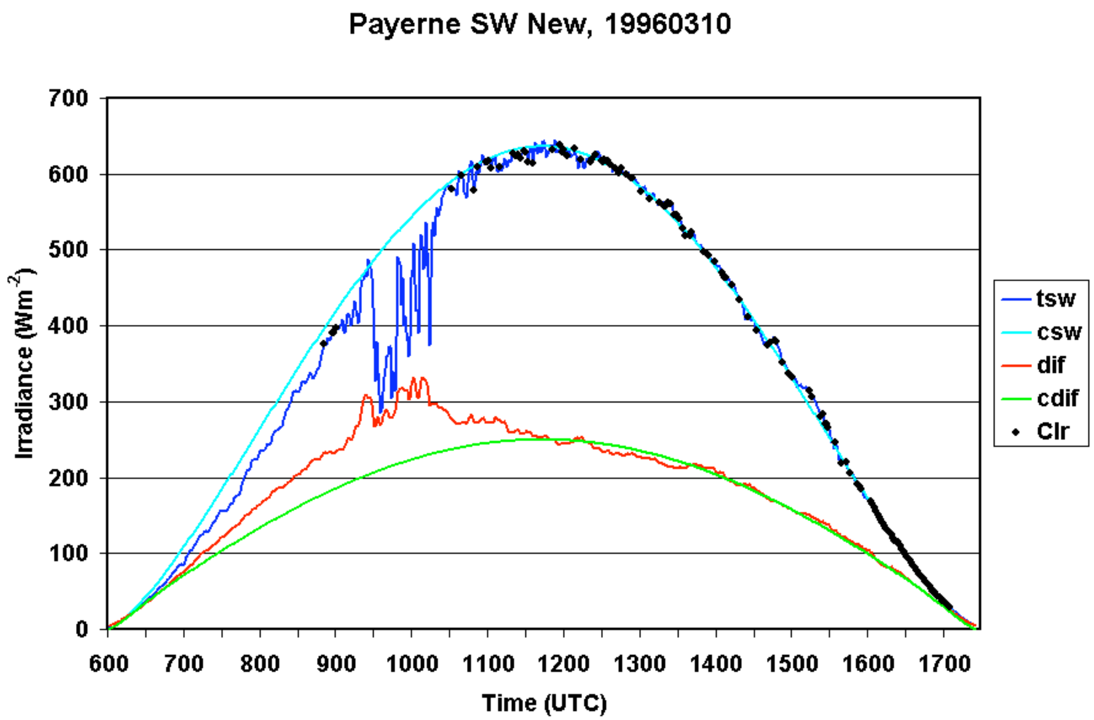
Average surface albedo this day is about 25%

Sutter M., B. Dürr, R. Philipona (2004), Comparison of two radiation algorithms for surface-based cloud-free sky detection, J. Geophys. Res., 109, D17202, doi:10.1029/2004JD004582.


Payerne Diffuse SW, 19960310
Diffuse
CosZ
0
50
100
150
200
250
300
350
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
DifSW
DifLim190
DifLim360


Allowable diffuse set to 360 Wm^{-2}


Allowed variability of the normalized diffuse ratio increased by an order of magnitude!


Payerne SW New, 19960310
Irradiance (Wm^{-2})
Time (UTC)
0
100
200
300
400
500
600
700
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
tsw
csw
dif
cdif
Clr